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PICKERING NGS 'B' INTERIM AQUATIC STUDY: ROUND WHITEFISH SPAWNING INVESTIGATIONS - 1984/85

Report No 87-181-K

J.S. Griffiths
Biologist
Biological Research Section
Chemical Research Department

ABSTRACT

Adult round whitefish (97 from 16 gillnet sets) were collected at Whitby West and Thickson Point in November & December, 1984. Average abundance was highest at Thickson Point. At both sites, catches were greater at 7 meters than at 3 m. Apparently different age structures at Pickering and Darlington suggest that distinct stocks may be spawning at the two sites. The age of peak abundance was 4+ for Pickering fish and 5+ for Darlington fish. Six round whitefish larvae were taken each year from spring benthic sled samples in 1984 and 1985. These larvae were collected over the 3-7 m depth range at Whitby West and Thickson Point. Substrate surveys suggested that spawning should be most successful over the 3 to 8 m depth range, due to smaller amounts of silt and sand present. Whitefish eggs incubated at 5 m depth near Pickering 'B' hatched 4-5 weeks ahead of those at Thickson Point, due to a temperature rise averaging 3 C°. Hatch advancement at other sites (temperature rise 1 C° or less) ranged from 1 to 2 weeks. Computer simulations based on thermograph temperatures indicated that the predicted date for 50% hatch coincided with observed hatch dates. Best survival (41% at hatch) was obtained at points east of Pickering (Simcoe, Richardson, Thickson). Computer simulations indicated that lower survival (22%) at the Pickering 5 m site was partly due to thermal effects. However, excessive sedimentation appeared to contribute to low survival at both Pickering (5 & 7m) sites and was especially severe at the Rouge River site (11% survival).

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EXECUTIVE SUMMARY

PICKERING NGS 'B' INTERIM AQUATIC STUDY: ROUND WHITEFISH SPAWNING INVESTIGATIONS - 1984/85

J.S. Griffiths
Biological Research Section
Chemical Research Department

A study of round whitefish spawning activity and success was conducted in the vicinity of Pickering NGS 'B' from the spring of 1984 to the spring of 1985. Study components included monitoring of adult whitefish abundance, population age structure, and growth from fall gillnet samples; sampling for eggs and newly hatched larvae in the spring; an examination of potential spawning sites at Thickson Point and Whitby West; and an in-situ incubation study with whitefish eggs incubated at 6 locations (from near the Rouge River west of Pickering to Thickson Point east of Pickering) over the winter of 1984-85.

A total of 97 adult round whitefish was collected from 16 gillnet sets at Whitby West and Thickson Point during late November and December, 1984. As in previous years, the largest catches were taken from the Thickson Point site, although the differences were not statistically significant (1982-1985 data). Significantly higher catches were obtained at the 7 m depth than at the 3 m depth over this period.

The age structure of round whitefish samples taken from Pickering (1979-1985 samples) appeared to differ from that of Darlington fish (1976-1984 samples). The age of peak abundance was 4+ for Pickering fish and 5+ for Darlington fish. Young fish (2+, 3+) were more common at Pickering, while older fish (5+, 6+) were more common at Darlington. These differences suggest that distinct stocks of round whitefish may be spawning at Pickering and Darlington. However, growth rates of the two groups were similar.

The whitefish age structure data indicated that the 1977 year class was exceptionally strong at both Pickering and Darlington, possibly the result of unusually cold temperatures during the winter of 1976-77.

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Computer simulations of thermal discharge effects indicated that small temperature rises (2 C°) would have little effect on egg survival during cold winters, but could substantially reduce survival during warm winters.

Only six round whitefish larvae were captured each year in 1984-85, despite a substantial sampling effort (108 and 96 samples, respectively) with the benthic sled. Larvae were captured at both the Whitby West and Thickson Point sites, in depths from 3 to 7 meters. They were not collected in samples taken at 9, 12 and 15 meters.

Bottom substrates from 1 to 12 m depth at Whitby West and Thickson Point were evaluated for spawning suitability from diver observations and photographs. Results suggested that spawning would be most successful over the 3 to 8 m depth range, and that Thickson Point may be more suitable due to smaller amounts of silt and sand present. However, substrates were extremely heterogeneous at both sites.

Round whitefish eggs incubated over the winter of 1984-85 in the immediate vicinity of the Pickering 'B' discharge hatched about 4 to 5 weeks before those incubated at Thickson Point. Temperatures at the Pickering site averaged about 3 C° above those at Thickson Point, although weekly average elevations as high as 4.5 C° were observed. Hatch advancement ranged from 1 to 2 weeks at the other sites tested, where temperature elevations averaged 1 C° or less. Computer simulations run with thermograph temperatures from each site indicated that the predicted date for 50% hatch would be a good estimator of field hatching times.

Best egg survival (approximately 41% hatch) was obtained at points east of Pickering (Simcoe, Richardson, Thickson). Survival approximated 22% at the Pickering 5 m site and 11% at the Rouge River site. Survival at hatch was not clearly defined for the Pickering 7 m site (due to post-hatch mortality), but earlier sampling suggested results comparable to the 5 m Pickering location. Simulations run with daily thermograph temperatures indicated that predicted survivals were higher than observed values at all locations, but the temperature elevations were sufficient to account for a substantial portion of the mortality observed at the Pickering 5 m site. The low survivals at the Rouge River and Pickering 7 m sites appear to be the result of excessive sediment accumulation.

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To Mr. C.W. Dawson
Environmental Studies and
Assessments Department
Design & Development - Generation

PICKERING NGS 'B' INTERIM AQUATIC STUDY:
ROUND WHITEFISH SPAWNING INVESTIGATIONS - 1984/85

1.0 INTRODUCTION

This report describes field studies of round whitefish spawning activity and success conducted in the vicinity of Pickering NGS 'B' over the period from the spring of 1984 to the spring of 1985. This work was conducted at the request of the Environmental Studies and Assessments Department and is part of the Pickering NGS 'B' Interim Aquatic Study. The Interim study (1982-1985) spans the commissioning period of Pickering 'B' and will be followed by a three year period of post-operational studies (1986-1988). During the course of the present investigation, power output from Pickering 'B' ranged from 2 units (April - May, 1984) to 3 units (December 1984 - April 1985). In addition, the adjacent Pickering 'A' station operated two of it's four units over most of this period.

One of the requirements of the post-operational study is to assess the effects of the combined thermal plumes from Pickering NGS 'A' and 'B' on the reproduction of coldwater fish. Round whitefish is the most abundant coldwater species thought to spawn in the area influenced by the plume and was selected as the study species to represent the coldwater fish community. An objective of the study was to develop techniques (benthic sled, suction pump, egg incubators) to enable the required assessment of effects to be carried out during the post-operational period. The spawning study was conducted at two sites east of Pickering (Whitby West and Thickson Point) because Haymes and Kolenosky (1984) identified these locations as providing the highest catches of round whitefish (suggesting spawning aggregations) in a comparative fall study extending from Scarborough to Port Hope.

During the present study, adult round whitefish were sampled with gillnets during their spawning period (November - December 1984) at Whitby West and Thickson Point. Attempts were made to collect round whitefish eggs using a suction pump in late December 1984 and March 1985. Larval tows (with a benthic sled) were made at these sites in the spring of 1984 and the spring of 1985. During the summer of 1984, potential spawning substrates in the vicinity of Thickson Point and Whitby West were examined and photographed by SCUBA divers. In

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addition, in-situ egg incubations were conducted throughout the winter of 1984-85, with round whitefish eggs placed in chambers at 6 sites, ranging from Thickson Point in the east to the Rouge River in the west. Two of these incubation chambers were located immediately offshore from the Pickering NGS 'B' discharge (at 5 and 7 m depths).

2.0 METHODS

2.1 Gillnet Survey

Gillnets were set weekly from November 20 to December 11, 1984 to sample adult round whitefish during the spawning period. Each net consisted of 8 panels, each 15 m in length, ranging from 3.8 cm to 12.5 cm mesh in 1.3 cm increments. Nets were set on the bottom, perpendicular to shore for 24 hour periods. During each fishing session, nets were set at depths of 3 m and 7m (depth of inshore end of the nets) at both the Whitby West and Thickson Point sites (Figure 1). Thus, a total of 16 gillnet sets was made. Surface and bottom temperatures were measured before and after each gillnet set. All coregonids and salmonids captured alive were released.

Fork lengths and weights were measured and scale samples taken from all salmonids and coregonids not released. Salmonid scales were sent to the Ministry of Natural Resources for ageing to supplement their Lake Ontario data base. Coregonid scales were used in age and growth determinations for the present report.

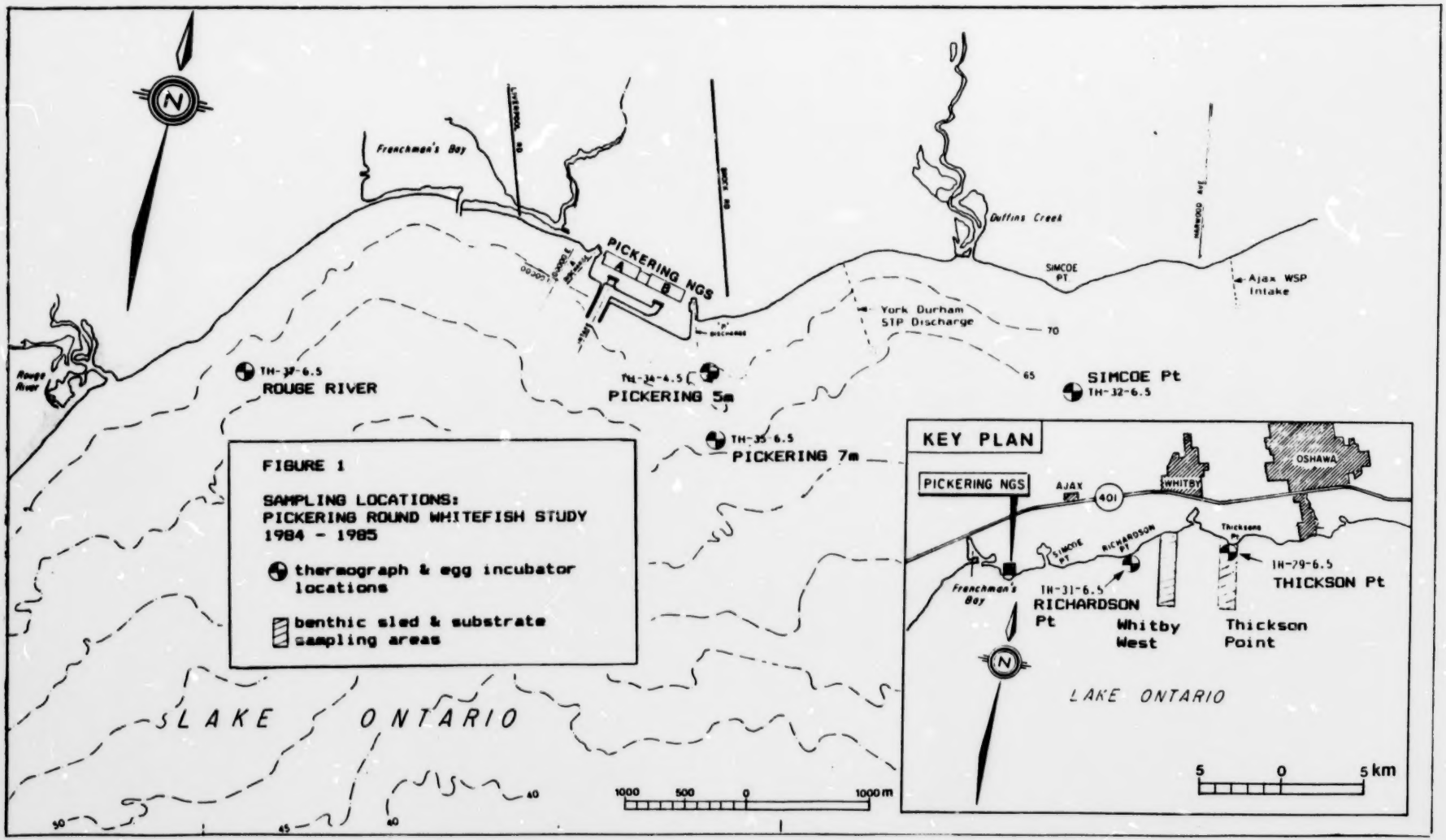
2.2 Benthic Sled Sampling for Round Whitefish Larvae

Spring benthic sled sampling was conducted at the Whitby West and Thickson Point locations (Figure 1). At each site, tows were made parallel to shore at depths of 3, 5, 7, 9, 12 and 15 meters. Tows were made during the day at a boat speed of 1 m/s for a duration of 5 minutes (approximately 300 m in length). The benthic sled tows were scheduled to begin in early April and extend over a four week period. However, in 1984, tows began on April 11 and were completed by April 26 (54 tows). In 1985, tows began on April 16 and were completed by April 30 (48 tows). Duplicate samples (from paired nets) were obtained on each sled tow.

All samples collected were preserved with 5% formalin and returned to the laboratory for analysis. Fish eggs and larvae were identified and counted.

2.3 Pump Sampling for Round Whitefish Eggs

It was proposed that a diaphragm pump would be used to sample eggs from the Whitby West and Thickson Point sites shortly after spawning (in mid to late December, 1984). This was attempted, but mechanical problems with the pump and adverse weather prevented the work from being carried out as planned. After several unsuccessful attempts during the midwinter period, samples were obtained using a gasoline powered 'trash


Frenchmen's Bay
Duffins Creek
PICKERING NGS
A
B
SIMCOE PT
Ajax WSP Intake
York Durham STP Discharge
70
65
Rouge River
TH-33-6.5
ROUGE RIVER
TH-34-4.5
PICKERING 5m
TH-35 6.5
PICKERING 7m
SIMCOE Pt
TH-32-6.5
FIGURE 1
SAMPLING LOCATIONS:
PICKERING ROUND WHITEFISH STUDY
1984 - 1985
thermograph & egg incubator locations
benthic sled & substrate sampling areas
LAKE ONTARIO
1000 500 0 1000m
KEY PLAN
PICKERING NGS
AJAX
401
WHITBY
OSHAWA
SIMCOE PT
RICHARDSON PT
Thickson Pt
Frenchmen's Bay
TH-31-6.5
RICHARDSON Pt
TH-29-6.5
THICKSON Pt
Whitby West
Thickson Point
LAKE ONTARIO
5 0 5 km

pump' in late March, 1985. The pump appeared satisfactory, as it was able to remove most fine or loose material from the lake bottom. Triplicate samples (approximately 2 m x 2 m) were obtained from 3, 5, 7 and 9 m depths at the Whitby West site. However, as no eggs or larvae were found, further sampling was not attempted.

2.4 Spawning Substrate Survey

The substrate along the Whitby West and Thickson Point benthic sled transects (from 1 m to 12 m depth) was examined in September, 1984, when water clarity was good. Divers made visual estimates of the substrate composition and took photographs of the substrate on the transect centre line and approximately 5 m on either side.

2.5 Round Whitefish Egg Incubation Experiment

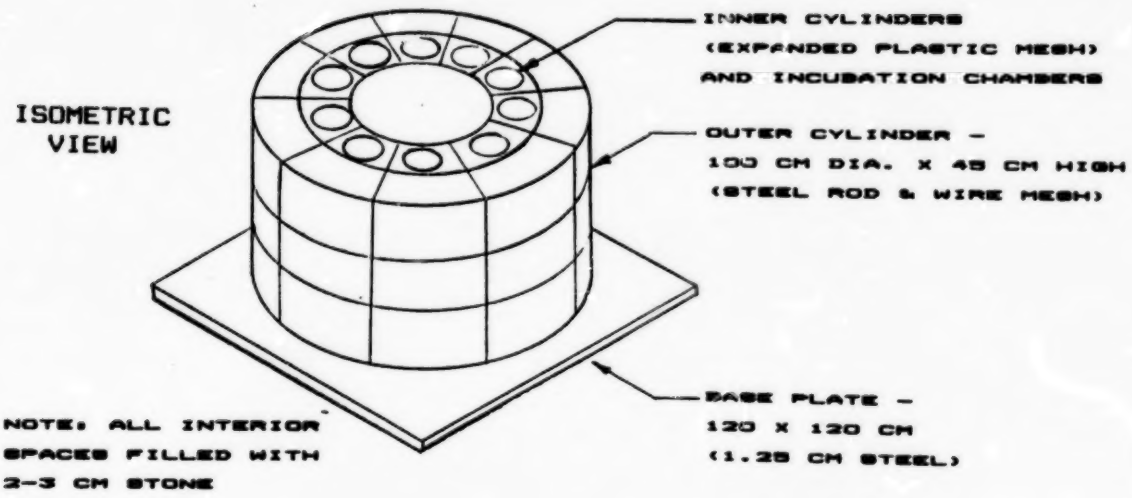
Six field egg incubators were constructed for this experiment. Each incubator consisted of an outer 100cm diameter x 45 cm high enclosed cylindrical wire cage, attached to a 120 cm x 120 cm x 1.25 cm steel base plate (Figure 2). Each incubator contained ten incubation baskets, made of stainless wire (1 mm mesh) and PVC plastic. These baskets were supported about 20 cm above the base plate by circular columns of wire and PVC mesh. The mesh size of all wire cage material (except the fine mesh cages) was about 1.5 cm. All areas within the incubator (including the egg baskets) were filled with 2 to 3 cm gravel. Once filled with gravel, the incubators were very heavy and thus resistant to the high wave forces produced by winter storms. The substantial mass of gravel surrounding the eggs was also expected to reduce the damaging effects of wave forces on the eggs, yet allow sufficient water movement for respiratory exchange.

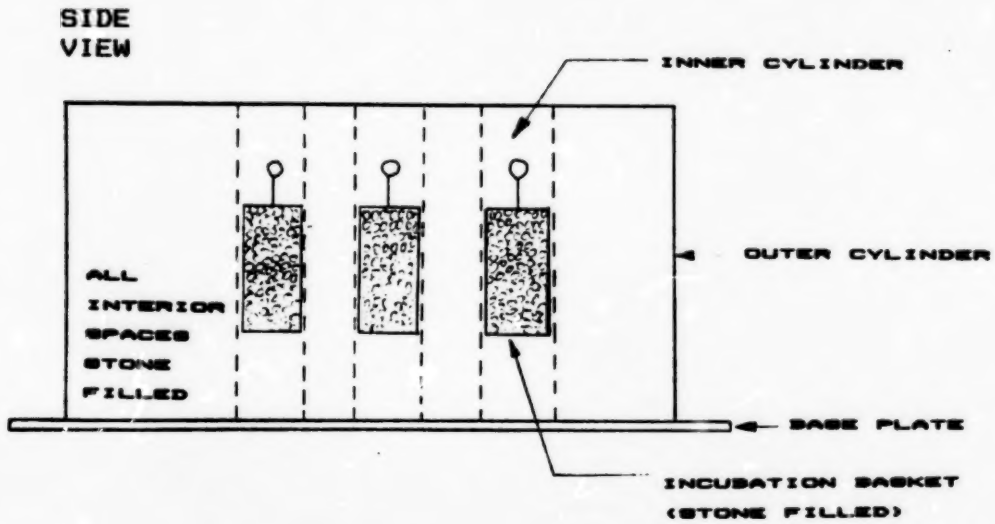
In September 1984, the incubators were placed on the lake bottom and filled with gravel. The egg baskets were not added at this time. The incubators were placed at 7 meters depth at the following locations: Thickson Point, Richardson Point, Simcoe Point, Pickering NGS 'B' discharge and east of the Rouge River (Figure 1). In addition, one incubator was placed at the 5 meter contour directly off the Pickering 'B' discharge.

Ripe round whitefish were collected with gillnets at the Whitby West site on December 11, 1984. Eggs from 3 or 4 females were stripped and fertilized (dry method) with milt from several males. The eggs were rinsed, well mixed and allowed to water harden. Then the eggs were added to the gravel filled incubation baskets (150 eggs/basket) which were placed by divers in the incubation chambers. After each basket was placed into the incubator, a gravel filled chamber (15 cm high) was added above the basket to provide additional protection (Figure 2). As it was not possible to install all of the incubation baskets on the day of fertilization, about half of the baskets were suspended from a buoy in the Pickering intake until the following morning.

FIGURE 2

ROUND WHITEFISH EGG FIELD INCUBATOR


ISOMETRIC VIEW
INNER CYLINDERS (EXPANDED PLASTIC MESH) AND INCUBATION CHAMBERS
OUTER CYLINDER - 100 CM DIA. X 45 CM HIGH (STEEL ROD & WIRE MESH)
BASE PLATE - 120 X 120 CM (1.25 CM STEEL)
NOTE: ALL INTERIOR SPACES FILLED WITH 2-3 CM STONE



A sample of eggs was returned to the laboratory and held in 3 to 4° C water. Examination of about 20 eggs/day over the following several days indicated that fertilization success approximated 100%. Incubating eggs were collected from the field incubators on five occasions (February 5, March 13, April 4, April 17 and April 26). Sampling dates were partly determined by weather conditions and boat availability. However, the first sampling date was timed to be past the period of maximum sensitivity to handling stress (Ontario Hydro Research Division Report 80-140-K). Sampling periods were also concentrated towards the end of incubation (April) to improve estimates of hatch success. On each sampling date, divers removed two egg cages (150 eggs/cage) from each incubator. The cages were transferred (in large water filled buckets) to the laboratory, where they were held overnight in a circulating water bath at Lake Ontario ambient temperatures. The following day, gravel was carefully removed from the chambers and all remaining eggs or larvae were recovered. The development stage reached was determined by microscopic examination of a number of eggs from each sample, using criteria modified from Brooke, 1975 (see OHRD Report 80-140-K for the 20 stages recognized). Comparisons were also made with laboratory incubated eggs (Pickering and Darlington stocks) which were being incubated at temperatures approximating Lake Ontario ambient.

Bottom temperatures were recorded continuously between December 1984 and April 1985, in the vicinity of each egg incubator, using thermographs operated by the Geotechnical and Hydraulic Engineering Department. In addition, bottom temperatures were measured by divers at the time of egg recovery and turbidity was also measured.

The round whitefish development time and survival models developed in the laboratory (OHRD Report 80-140-K) were used with the thermograph records to predict development stages and survivals for each site on the dates of sampling. Predictions were compared with observed results.

The original laboratory data (OHRD Report 80-140 K) indicated that the sensitivity of round whitefish eggs to thermal stress changed as embryonic development proceeded. Three temperature vs survival models were fitted. The first (Block 1) covered the period from fertilization to development stage 9 (formation of a free tail-bud), the second (Block 2) from stage 9 to stage 19 (last pre-hatch stage) and the last (Block 3) covered stages 19 to 20 (the hatching period). In addition, three temperature vs development models were fitted to allow estimation of the time required to complete each development block at given temperatures. In the present study, these models were used with daily mean temperatures (from the thermograph records) to predict development and survival at each incubation site. The simulation procedure is described below.

Beginning with the date of fertilization, the expected percentage of Block 1 development was computed from the recorded temperature. This calculation was repeated for each successive day and results accumulated until the calculations indicated that Block 1 was complete. Then the

Block 2 and Block 3 models were used in succession until the calculations indicated that hatch was complete. For each daily interval used in the simulation, the appropriate (Block 1 through Block 3) survival model was used to compute and accumulate the expected mortality. The simulation procedure was programmed for use on a Sinclair 'QL' microcomputer.

3.0 RESULTS AND DISCUSSION

3.1 Gillnet Survey of Spawning Adults

A total of 314 fish was caught during 16 gillnet sets over the period of November 20 to December 11, 1984 (Appendix 1A). Round whitefish was the most abundant species, with 97 fish captured. Other abundant species were white sucker (63), brown trout (55), lake trout (29), alewife (17) and white bass (15).

More round whitefish were taken at the Thickson Point sites (63; average CUE = 7.88 fish/net) than at the Whitby West sites (34; average CUE = 4.25). At both locations, round whitefish were more abundant at the 7 meter depth (CUE = 8.63) than at 3 meters (CUE = 3.50). Similar patterns of catch were noted in whitefish surveys conducted in 1982 (OHRD Report 83-435-K) and 1983 (OHRD Report 84-341-K). However, the average catch in 1984 (6.06 round whitefish/net) was higher than values for the previous two years (CUE = 3.25 to 3.75). The largest single-net catch (29 round whitefish) was taken at the 7 m Thickson Point site on December 11, when the temperature was 3.1°C. In previous study years (1981 to 1983), the largest single-net catches have also been taken at this site over the December 3 to December 8 period.

Catch data were analyzed with a two-way ANOVA (location x depth) for log(n+1) data. Results indicated that neither location ($F_{1,12}$ = 2.02) nor depth ($F_{1,12}$ = 2.60) significantly affected mean catch. However, a similar analysis using catch data for the 1982-1985 period indicated a significantly higher catch at 7 meters ($F_{1,52}$ = 12.36) than at 3 meters (Pope, pers. comm.). Again, the average catch at Thickson Point exceeded that at Whitby West, but this difference did not quite attain statistical significance ($F_{1,52}$ = 3.62).

Forty-nine round whitefish were aged from scale samples taken in the 1984 gillnet sampling. The age structure of this sample (Appendix 1B) is shown in Figure 3a. In this figure, the numbers of fish in each age class have been computed as a percentage of the total sample. Results indicate that fish aged 4+ were the most abundant group (36.7%) in the Pickering sample, followed by 3+ (28.6%) and 5+ fish (24.5%). Together, these three age groups account for almost 90% of the spawning fish sampled. The age structure of 200 round whitefish sampled from Darlington in 1984 (OHRD Report 87-82-K) appears to differ (Figure 3a). Whitefish aged 5+ were the most abundant group (30%), with 4+ and 6+ fish each contributing about 20% to the sample. In addition to the age

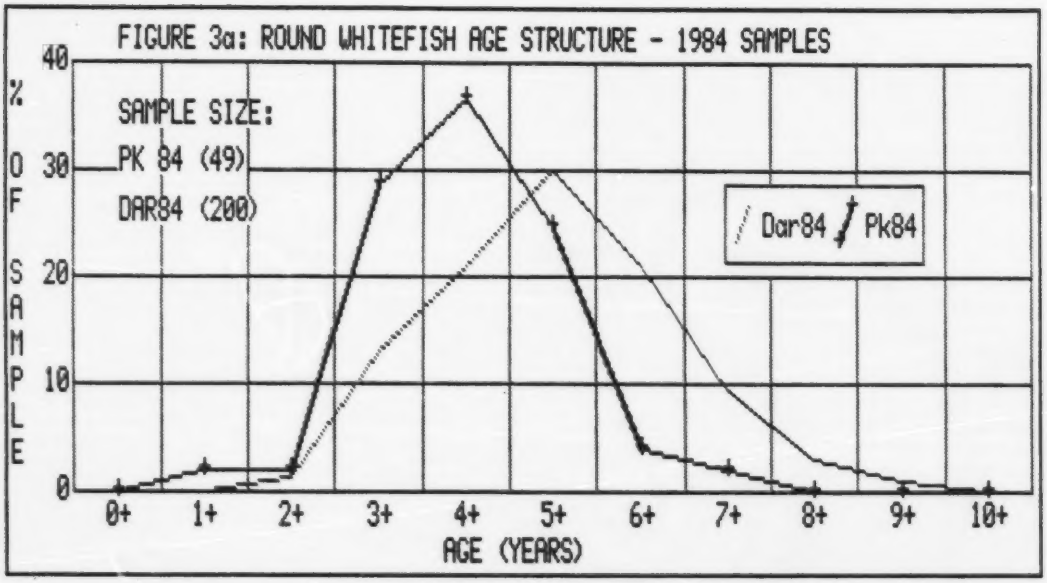


FIGURE 3a: ROUND WHITEFISH AGE STRUCTURE - 1984 SAMPLES
SAMPLE SIZE:
PK 84 (49)
DAR84 (200)
Dar84
Pk84
% OF SAMPLE
0
10
20
30
40
0+
1+
2+
3+
4+
5+
6+
7+
8+
9+
10+
AGE (YEARS)

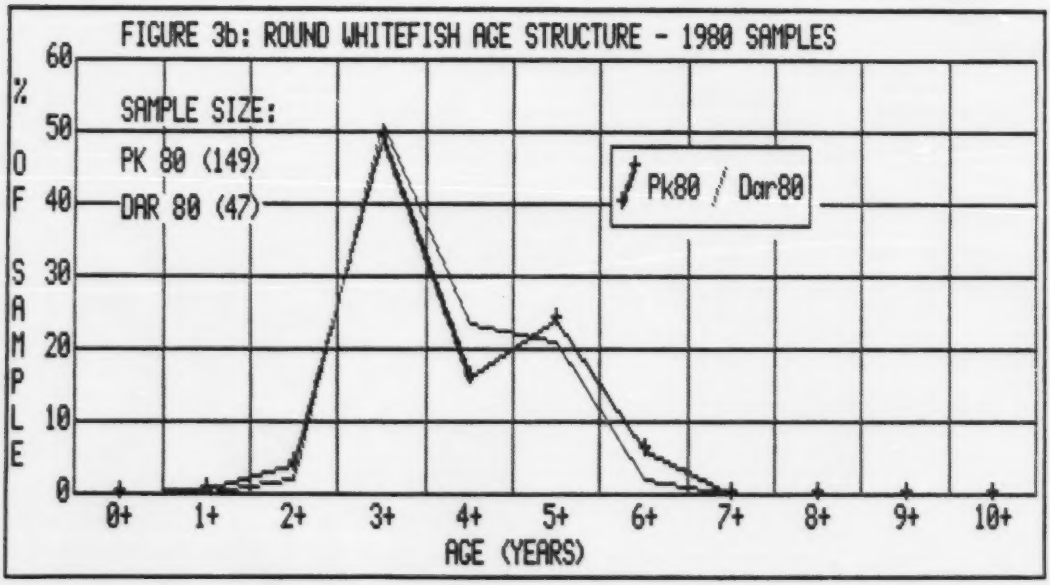


FIGURE 3b: ROUND WHITEFISH AGE STRUCTURE - 1980 SAMPLES
SAMPLE SIZE:
PK 80 (149)
DAR 80 (47)
Pk80
Dar80
% OF SAMPLE
0
10
20
30
40
50
60
0+
1+
2+
3+
4+
5+
6+
7+
8+
9+
10+
AGE (YEARS)

of peak abundance appearing to occur one year later at Darlington, the Darlington samples contained fewer age 3+ fish and more old fish (ages 6+ and older).

Spawning round whitefish at Pickering and Darlington have been sampled concurrently in only one other year (1980). At that time, Ontario Hydro sampled in the Pickering area, while the Ministry of Natural Resources (MNR) sampled at Darlington and points further east (Haymes & Kolenosky, 1984). Age distribution results for those 1980 whitefish samples are plotted in Figure 3b. Results for the Pickering and Darlington fish are virtually identical, but differ substantially from 1984 samples (Figure 3a). In 1980, whitefish populations were dominated by fish aged 3+ (1977 year class), which contributed about 50% to both Pickering and Darlington samples. Only moderate numbers (15 to 25%) of 4+ and 5+ fish were present, and old fish (>6+ years) were not collected from either site.

Due to the similarity in age structure for Pickering and Darlington samples obtained in 1980, it has been assumed that these fish form a single population along the north shore of Lake Ontario (Haymes, pers. comm.). However, the results of 1984 sampling (Figure 3a) suggest that two distinct populations may exist. In order to further investigate this possibility, all age data collected from Pickering and Darlington over the 1976 to 1985 period have been examined in detail.

Results from the first 3 years at Pickering (1979-1980; Figure 4a) clearly demonstrate the dominance of the 1977 year class as it was sampled at ages 2+ to 4+, respectively. In 1979, this year class (age 2+) accounted for 40% of the catch. By 1980, the '77 year class appeared to be fully recruited into the spawning population, and made up 50% of the sample. By 1982, the 1977 year class (age 5+) still accounted for 30% of the sample (Figure 4b). However, at this time, fish of age 4+ again became dominant. Over the 1981 to 1984 period, fish aged 4+ have generally been the most abundant age group at Pickering, accounting for about 33 to 37% of the catch. In 1985, this age group was unusually dominant, contributing 57% to the total sample (Figure 4c). These results suggest another strong year class, hatched in 1981. Further evidence of a strong 1981 year class is provided from 1984 samples (age 3+ - 29%) and 1983 samples (age 2+ - 12%).

In summary, the age structure data from Pickering samples suggests that at least two strong year classes (1977, 1981) have occurred in recent years, and that presence of these exceptional year classes has tended to increase the variability of the whitefish age structure as these strong year classes passed through the population. However, in 5 of the 7 sample years, fish aged 4+ have been the most abundant age class, accounting for 33 to 57% of the samples. Fish aged 5+ have never been the dominant age group (although they outnumbered 4+ fish in 1980), and older fish (age >6+ years) have been quite rare.

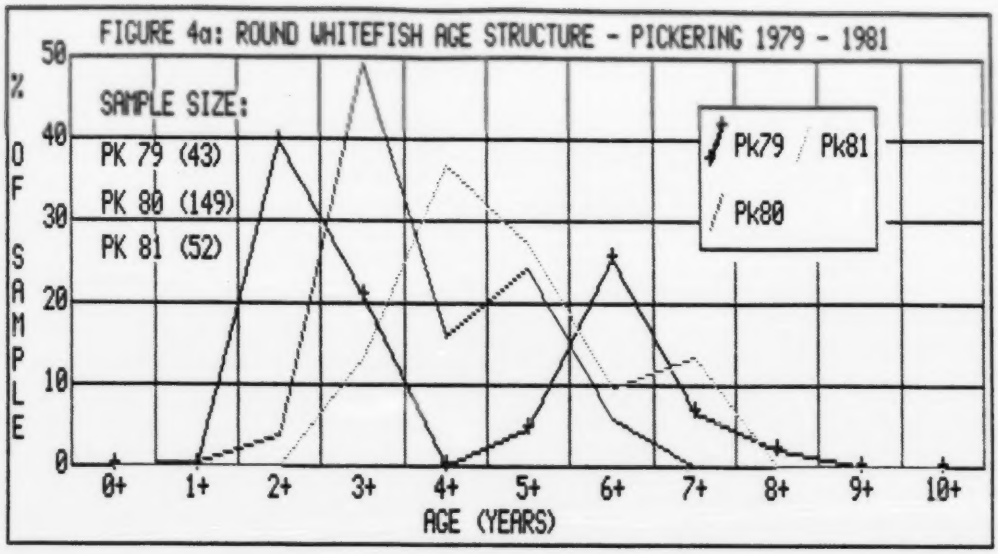


FIGURE 4a: ROUND WHITEFISH AGE STRUCTURE - PICKERING 1979 - 1981
% OF SAMPLE
SAMPLE SIZE:
PK 79 (43)
PK 80 (149)
PK 81 (52)
Pk79 / Pk81
/ Pk80
0
10
20
30
40
50
0+ 1+ 2+ 3+ 4+ 5+ 6+ 7+ 8+ 9+ 10+
AGE (YEARS)

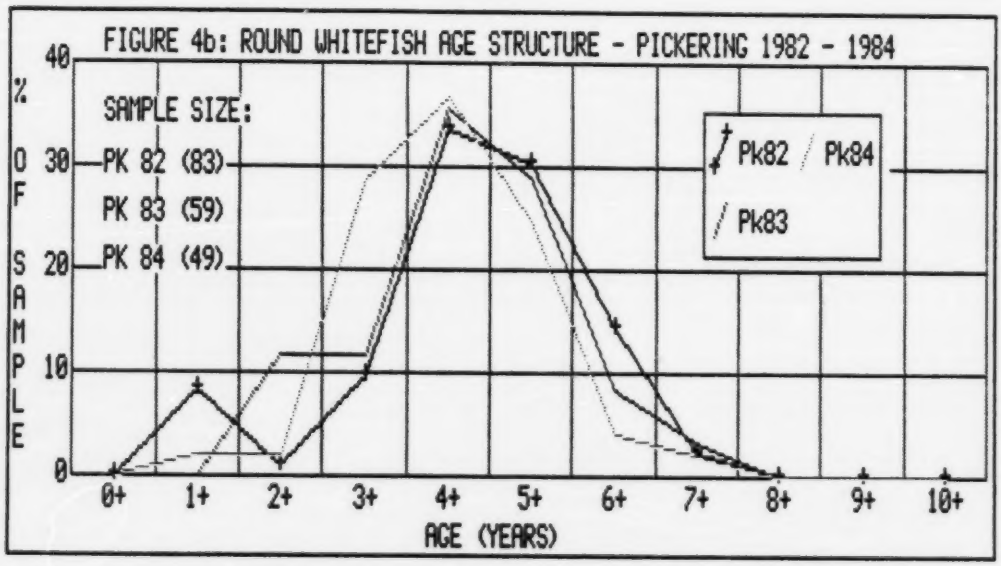


FIGURE 4b: ROUND WHITEFISH AGE STRUCTURE - PICKERING 1982 - 1984
% OF SAMPLE
SAMPLE SIZE:
PK 82 (83)
PK 83 (59)
PK 84 (49)
Pk82 / Pk84
/ Pk83
0
10
20
30
40
0+ 1+ 2+ 3+ 4+ 5+ 6+ 7+ 8+ 9+ 10+
AGE (YEARS)

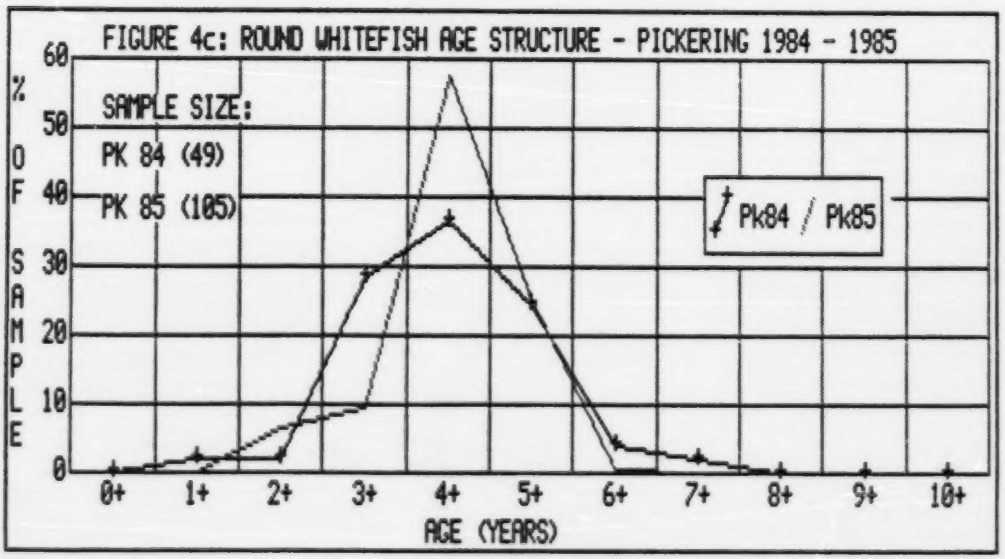


FIGURE 4c: ROUND WHITEFISH AGE STRUCTURE - PICKERING 1984 - 1985
% OF SAMPLE
SAMPLE SIZE:
PK 84 (49)
PK 85 (105)
Pk84 / Pk85
0
10
20
30
40
50
60
0+ 1+ 2+ 3+ 4+ 5+ 6+ 7+ 8+ 9+ 10+
AGE (YEARS)

Age structure data for whitefish collected from Darlington are available for only 4 sample years (1976, 1977, 1980, 1984). Scales from the 1985 sampling have not yet been analyzed. Samples from 1977 and 1984 both showed peak abundance at age 5+, while 6+ was the most abundant age class in 1976 samples (Figure 5a). It should be noted that only 16 round whitefish were collected in 1976 (compared with samples ranging from 47 to 200 fish in other years). Thus, the 1976 data should be viewed with caution. The age structure of the 1980 Darlington sample (Figure 5b) differs substantially from results of other years, due to the influence of the strong 1977 year class (age 3+ fish here).

The mean age structure for Pickering and Darlington samples (averaged over all sample years) is shown in Figure 6. Results are similar to the comparison of 1984 samples (Figure 3a). The age of peak abundance was 4+ for Pickering samples and 5+ for Darlington samples. The Pickering samples were also characterized by a greater average abundance of fish aged 2+ and 3+, while older fish (5+, 6+) were more common in Darlington samples.

Covariance analysis was used to determine whether the differences suggested by Figure 6 were statistically significant. For this analysis, the data were split into two sets. In the first data set, percentage compositions were compared over the recruitment period (up to the age of peak abundance). After fitting regressions (% abundance vs age) for the Pickering and Darlington data, a test of adjusted means (at a common mean age of 2.8 years) was performed. While the average Pickering abundance at this age (21.6%) was greater than that at Darlington (12.9%), this difference did not quite attain statistical significance ($F_{1,35} = 3.60$; $F_{(0.005)} = 4.15$). A similar comparison for the descending limbs of the curves in Figure 6 indicated that at a common mean age of 5.89 years, the average Darlington abundance (19.6%) was not significantly larger than the Pickering value (14.6%; $F_{1,50} = 2.79$).

Thus, while the general trend of results suggests that the age structure of Pickering round whitefish differs from that of Darlington fish, these apparent differences cannot be statistically validated from present data. It is suggested that the presence of some exceptionally strong year classes (1977, 1981) may have contributed to the high variability of the data.

Some incidental observations also suggest differences between Pickering and Darlington round whitefish. Eggs collected from several Pickering fish (Whitby West, Thickson Point) in December 1984, for field incubation studies were uniform pale yellow colour, while eggs from several Darlington females (collected for other laboratory studies) were uniformly deep orange. Both groups of eggs were incubated in the laboratory and maintained their colour difference throughout the incubation period. A second possible difference concerns the age at maturity. Haymes and Kolenosky (1984) reported that 17% of age 2+ females and 90% of age 3+ females were sexually mature. All females

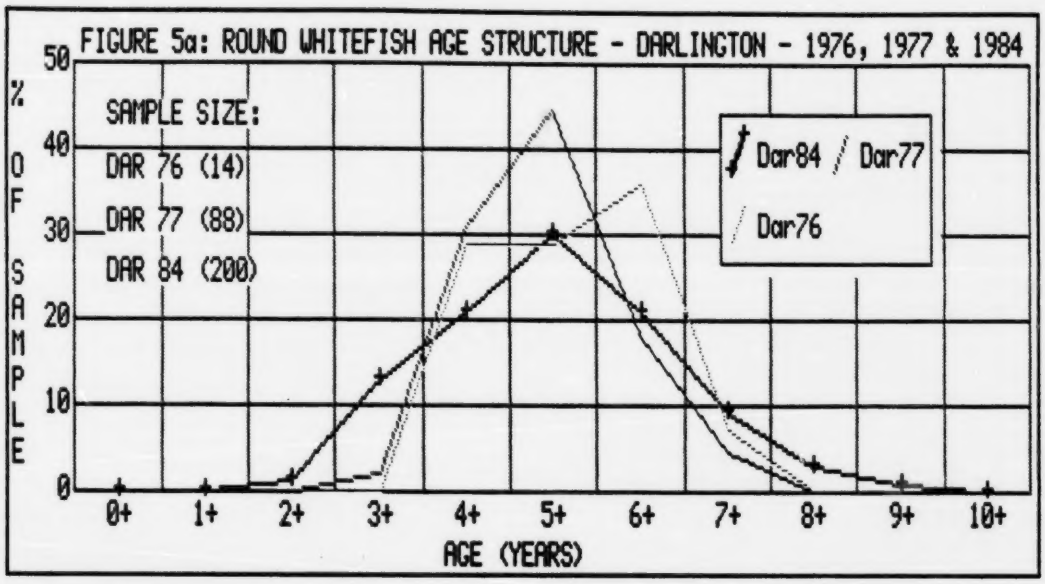


FIGURE 5a: ROUND WHITEFISH AGE STRUCTURE - DARLINGTON - 1976, 1977 & 1984
% OF SAMPLE
SAMPLE SIZE:
DAR 76 (14)
DAR 77 (88)
DAR 84 (200)
Dar84 / Dar77
Dar76
0
10
20
30
40
50
0+
1+
2+
3+
4+
5+
6+
7+
8+
9+
10+
AGE (YEARS)

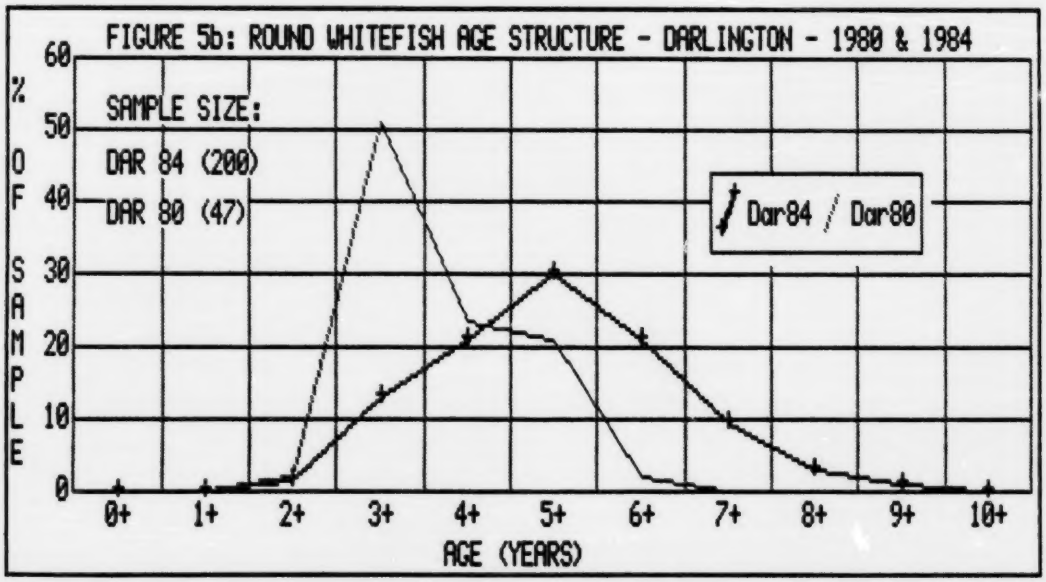


FIGURE 5b: ROUND WHITEFISH AGE STRUCTURE - DARLINGTON - 1980 & 1984
% OF SAMPLE
SAMPLE SIZE:
DAR 84 (200)
DAR 80 (47)
Dar84 / Dar80
0
10
20
30
40
50
60
0+
1+
2+
3+
4+
5+
6+
7+
8+
9+
10+
AGE (YEARS)

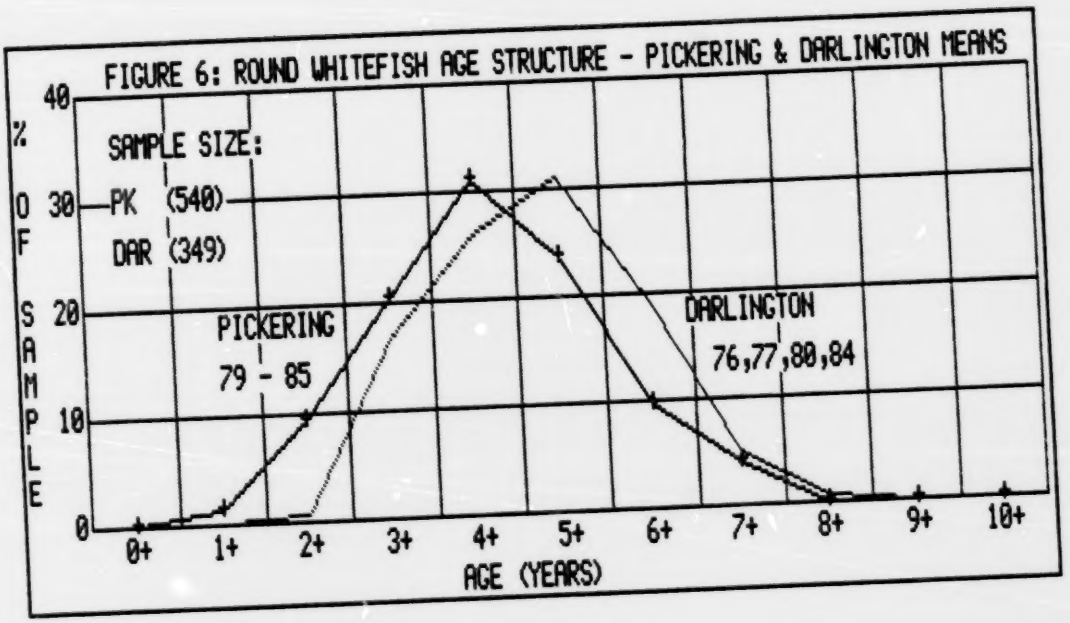


FIGURE 6: ROUND WHITEFISH AGE STRUCTURE - PICKERING & DARLINGTON MEANS
% OF SAMPLE
40
30
20
10
0
SAMPLE SIZE:
PK (540)
DAR (349)
PICKERING
79 - 85
DARLINGTON
76,77,80,84
0+
1+
2+
3+
4+
5+
6+
7+
8+
9+
10+
AGE (YEARS)

aged 4+ or older were mature. These results were based on combined Pickering (1979, 1980) and Darlington (1980) samples. In 1984, fecundity vs age data were obtained from Darlington samples (OHRD Report 87-82-K). These results indicated a very low fecundity for age 4+ fish (approximately 3000 eggs/female) and a fecundity of zero for females aged 3+. In 1985, attempts were made to obtain additional small fish to improve the fecundity estimate, but very few fish under 37 cm in length (average for a fish aged 4+) were present. Thus, it appears that very few mature round whitefish females of age 4+ or less are present at Darlington. The fish taken at Darlington in 1980 (9 age 3+ females; all mature) were from the dominant 1977 year class and do not appear to be representative of current conditions at the site.

The differences observed between Pickering and Darlington round whitefish are typical of those which might be associated with differing growth rates. Darlington fish, which seem to be recruited to the adult population at a later age, probably mature later, and show greater longevity, might be expected to show a slower growth rate. Although these fish spawn only about 15 km apart along the north shore of Lake Ontario, little is known about their offshore distribution during the remainder of the year. Thus, the possibility of different feeding areas, and hence different growth rates, does not seem unreasonable. Growth of the two groups is shown in Figure 7. It is apparent that the age vs length (Figure 7a) and age vs weight (Figure 7b) relationships do not differ substantially. The only apparent differences occur at the extremes of available data, where sample sizes are small. Thus, it must be concluded that there are no real differences in growth rate between Pickering and Darlington fish.

Such data do not support the hypothesis that Pickering and Darlington samples are from two distinct stocks. However, similarity of growth rates does not negate the possibility that separate stocks spawn at Pickering and Darlington, as the two groups could share common feeding areas, or utilize separate areas of similar productivity.

From present information, it is not possible to determine whether Pickering and Darlington round whitefish are two stocks, or a single population in which the older fish (for reasons not presently known) tend to spawn in the Darlington area, while the younger fish tend to spawn in the Pickering (Whitby West, Thickson Point) area. It is suggested that this question may be of more than academic interest, as any adverse impacts from operation of Pickering or Darlington may have a greater effect on small, discrete stocks than on a large well mixed population along the Lake Ontario north shore. Clearly, the potential for loss of genetic diversity would be greater if small discrete stocks are present.

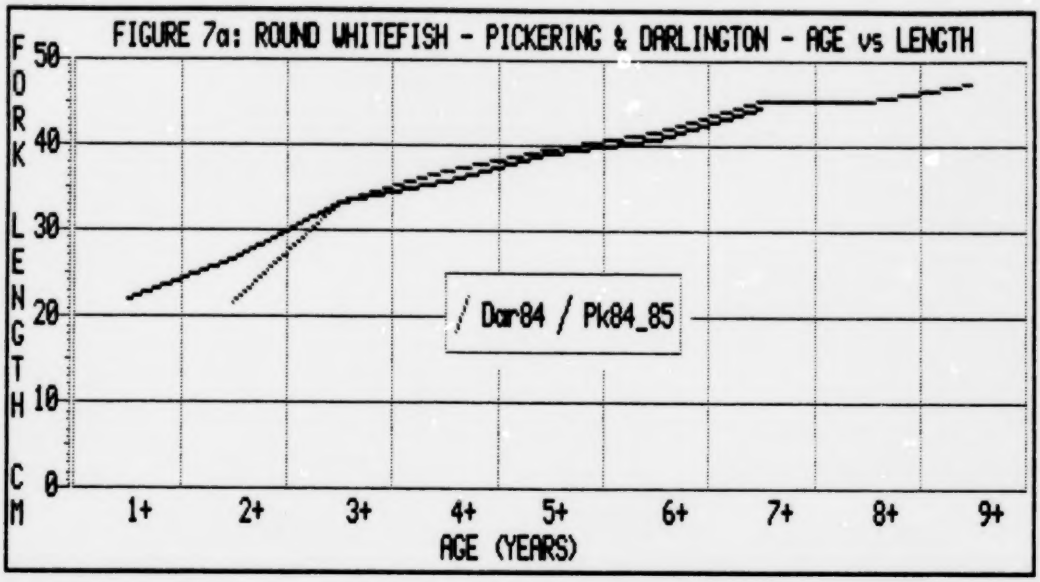


FIGURE 7a: ROUND WHITEFISH - PICKERING & DARLINGTON - AGE vs LENGTH
FORK LENGTH CM
50
40
30
20
10
0
/ Dar84 / Pk84_85
1+
2+
3+
4+
5+
6+
7+
8+
9+
AGE (YEARS)

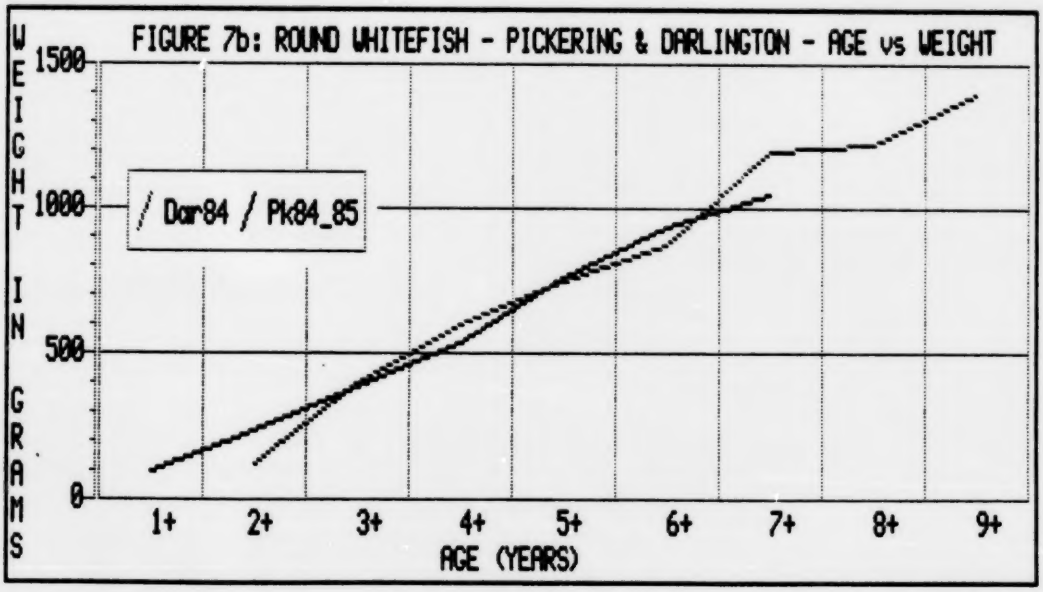


FIGURE 7b: ROUND WHITEFISH - PICKERING & DARLINGTON - AGE vs WEIGHT
WEIGHT IN GRAMS
1500
1000
500
0
/ Dar84 / Pk84_85
1+
2+
3+
4+
5+
6+
7+
8+
9+
AGE (YEARS)

The 1977 year class was exceptionally strong, as indicated by both Pickering and Darlington samples. It is interesting to note that the winter of 1976-77 was unusually severe (Scavia et al, 1986; Assel et al, 1984). A larger than normal ice pack developed along the north shore of Lake Ontario, and for a period, much of the lake was ice-covered. The winter of 1980-81 (another strong year-class) was less severe, but still colder than average for the Lake Ontario region (O'Gorman et al, 1986). Unusually cold conditions might benefit round whitefish in a number of ways:

1. A nearshore ice pack should protect incubating eggs from wave damage associated with winter storms.

2. The north shore of Lake Ontario is largely protected from northerly winds associated with extremely cold weather, hence turbidity and movement of fine sediments would likely be reduced.

3. Northerly winds would tend to promote upwelling of clear, cold water from the lake bottom. In addition to minimizing turbidity, very cold water would directly enhance round whitefish egg survival. Laboratory studies (OHRD Report No 80-140-K) indicated that the best egg survival (88.6%) occurred at the lowest temperature tested (1.7°C).

It should also be noted that in the above laboratory study, simulations were run using Oshawa water intake temperatures for winters from 1953 to 1977. Best egg survival (84.6%) was predicted for the winter of 1976-77. Also, Haymes and Kolenosky (1984) observed that the strong 1977 round whitefish year class coincided with strong year classes of other coregonids (lake whitefish and cisco) in other parts of Lake Ontario. While it is recognized that factors other than the direct effect of temperature on egg survival may have contributed to this strong year class, round whitefish are especially sensitive to thermal effects during embryonic development. In the simulations previously mentioned, the lowest predicted survival for ambient temperatures (77.1%) occurred in 1953-54, a winter which was extremely mild (Assel et al, 1984). While this predicted survival is only 7.5% lower than that predicted for the 1976-77 winter, it should be noted that effect of a moderate stress (from thermal discharge heating) would differ substantially during these years. Addition of a 2C° ΔT would not change the predicted survival for the 1976-77 winter, but the predicted survival for the 1953-54 winter would decline to 47.5%.

3.2 Benthic Sled Sampling for Round Whitefish Larvae

Catches of round whitefish larvae were quite low during both years. In 1984, six larvae were collected from 108 samples (54 paired tows) which filtered approximately 6400 m^3 of lakewater (Appendix 2A). Tows were conducted over the April 12 to April 25 period. On April 24, one round whitefish larvae was collected from the 3 meter depth at Whitby West, and two larvae were collected from the 7 meter depth at this site. On

April 25, one round whitefish larvae was collected from the 5 meter depth at Thickson Point, and two were taken from the 7 meter depth.

In 1985, six larvae were collected from 96 samples (48 paired tows) which filtered approximately 5650 m^3 of water (Appendix 2B). Tows were conducted over the April 16 to April 30 period. On April 19, two round whitefish larvae were collected from the 3 meter tow at Thickson Point, while one larva was collected from the 7 meter depth. On April 22, a single round whitefish larva was collected from the 7 meter depth at Thickson Point and two larvae were collected from 5 meters on April 25. No larvae were collected from the Whitby West sampling locations in 1985. Approximately 38% of the 1985 sampling effort occurred in this area, compared with 33% in 1984 (Appendix 2).

Although the total catch of round whitefish in the present study was quite low (6/year), results were somewhat better than in previous study years (OHRD Report 83-351-K). In 1979, 1981 and 1982, only 1 round whitefish larvae was taken in each year. In 1982, approximately 7000 m^3 of lakewater was sampled with bottom townets and the benthic sled. In 1983, the benthic sled was used for tows perpendicular to shore at Thickson Point and Whitby West. Sampling approximately 9900 m^3 of water yielded a catch of 2 round whitefish larvae. Thus, present catches, based on a smaller sampling effort, suggest that shore-parallel benthic sled tows may be more efficient at capturing round whitefish larvae than tows made perpendicular to shore. Shore-parallel tows do have an obvious advantage, as they indicate the depth of capture. In the present study (both years), 6 larvae were taken at 7 m, 3 were taken at 5 m, and 3 were taken at 3 m depth. No larvae were taken in tows at 9, 12 and 15 meters.

The data presently available allow at least a crude estimate of the capture potential, and hence, the efficiency of the benthic sled. The size of the population spawning at Pickering (Whitby West and Thickson Point) is not known, but the <u>minimum</u> number of spawners can be estimated. The age structure curve (Figure 6) indicates that over the ages 4+ to 7+ (following recruitment to the adult population), the abundance of each successive age class declined by an average of 44%. This value appears to be the average annual mortality rate for the adult population.

Over the 1979 to 1985 period, the average minimum removal from the adult population due to Ontario Hydro sampling (fish retained for age/growth analysis) has been 77 fish/year. If it is conservatively assumed that <u>all</u> the observed mortality has been due to this sampling (natural mortality is assumed to be zero), then the spawning adult population would have to be at least 175 fish (77/0.44). This is an extremely conservative estimate of the minimum adult population size, as the apparent mortality rate for Darlington fish is almost identical, yet

round whitefish at Darlington have been sampled in only 4 years over the 1976 to 1984 period, while Pickering fish were sampled yearly since 1979. Hence, it is likely that our sampling at Pickering is only a small component of the total mortality, and the actual population size is substantially larger than this minimum estimate.

However, if the minimum size of the spawning stock at Pickering is assumed to be 175 fish, it follows that about 100 fish would be left after the fall gillnet sampling. Using the age distribution for the Pickering spawners, plus the fecundity vs age relationship developed for Darlington (OHRD Report 87-82-K) it is estimated that 50 females would produce about 295,000 eggs. Based on field incubation studies at Thickson Point (described later in this report), it is estimated that about 40% (118,000) of these eggs would hatch. The Thickson Point and Whitby West sites are about 3 km apart. It is assumed that newly hatched larvae from these sites might be found up to 1 km on either side of these sites and would be located between the 3 m and 12 m depth contours, which are about 2 km apart. Thus, it is assumed that the 118,000 larvae would be located within a rectangle 5 km long by 2 km wide, with an area of 10 million square meters. The resulting average density would be 1.18×10^{-2} larvae/m^2. While it is recognized that larvae may not be uniformly distributed over this area, it seems likely that the intensity of sampling in 1984-85 (108 and 96 samples) would be sufficient to overcome much of the effect of larval 'patchiness'.

In the course of a 300 meter long benthic tow, each sled net would cover approximately 150 m^2 of bottom. If the sled were capable of capturing all the larvae within this area, then an average capture rate of 1.77 larvae/net would be expected. It is assumed that most larvae would be within a few centimeters of the bottom, a supposition supported by laboratory benthic sled studies (OHRD report in preparation) and previous laboratory behavioral studies (OHRD Report 83-57-K). Thus, a total of 191 larvae should have been captured in 1984 and 170 larvae should have been captured in 1985. Actual captures (6/year) indicate a maximum efficiency of 3.1% and 3.5%, respectively.

It is interesting to compare these values with efficiency estimates derived from laboratory studies of a 1/3 scale benthic sled towed in a flume (OHRD Report in prep.). Preliminary tests suggested that the sled was very effective in capturing round whitefish larvae (>50% of available larvae) from a smooth concrete flume bottom. When a pebble substrate (1-2 cm material) was added to the flume, capture efficiency (considering the relative width of the sled nets vs the flume width) declined to 12%. Addition of a layer of cobble (5-10 cm material) further reduced the capture efficiency to 4.9%. The decrease in sled efficiency appeared to be the result of two factors. Although the larvae seldom made obvious movements to avoid capture, the increased irregularity of the substrate provided numerous small depressions which could not be sampled by the sled nets. Thus, larvae within a few centimeters of the bottom could not be readily captured. Also, the irregular surface caused the sled to bounce several centimeters off the bottom, further reducing its effectiveness. Since much of the substrate

at the Whitby West and Thickson Point sites is composed of relatively large, irregular material (cobble or boulder, see subsequent report section), it is not surprising that larval catches in the field were low. While the estimated maximum efficiency for the field prototype sled was comparable to that observed for the 1/3 scale laboratory model, it is likely that actual whitefish populations are much larger than the estimates used here, and efficiency of the prototype sled is considerably lower than present estimates.

3.3 Spawning Substrate Survey

Results from the diver survey of substrates from 1 to 12 meters depth at the Whitby West and Thickson Point sites are listed in Appendix 3A. Additional information was derived from substrate photographs taken at each depth. These data are in Appendix 3B.

The diver observations consisted of visual percentage estimates for various substrate materials, ranging in size from boulders to silt. The size classification used as a guide for these estimates is listed in Appendix 3C. The substrate composition for each depth at the Whitby West site is shown in Figure 8. In each pie chart, the values are estimates of percentage cover for the respective substrate materials. The plots indicate that inshore substrates (1 to 6 meters) were dominated by cobble, sand and boulders. At 7 meters, 40% hardpan clay was present, while over the 8 to 10 meter range, large slate slabs made up from 35 to 80% of the substrate. Silt (from 3 to 15%) was present at 8, 11 and 12 meter depths.

Thickson Point substrates (Figure 9) differed somewhat from those at Whitby West. Sand dominated the 1 meter and 2 meter depths, but little or no sand was present from 3 meters to 8 meters. Over this depth range, cobble made up from 49 to 80% of the substrate. Substantially more clay was observed than at Whitby West, accounting for from 15 to 30% of the substrate over the 5 meter to 9 meter depth range. The clay was in the form of hardpan patches or as fines cementing the spaces between stones in cobble or boulder areas. Small amounts of silt (estimated at 1%) were observed over the 5 to 7 meter range, but substantial accumulations of silt (10 to 25%) were restricted to depths of 9 meters or more. Moderate amounts of sand (10 to 25%) were again observed from 10 to 12 meters.

The factor most likely to limit spawning success at these sites is the amount of fine grained, potentially mobile sediments which could cover incubating eggs, leading to death by suffocation. In Figure 10A, the percentage of total fines (sand, silt) at Whitby West is shown vs depth. A similar plot for Thickson Point is shown in Figure 10B. Clay was not considered among the 'total fines' as most of the clay appeared to be in compacted deposits which would be less susceptible to erosion or movement. At Whitby West, the plot suggests that spawning is most

FIGURE 8: WHITBY WEST SUBSTRATE COMPOSITION (ESTIMATED BY DIVERS)

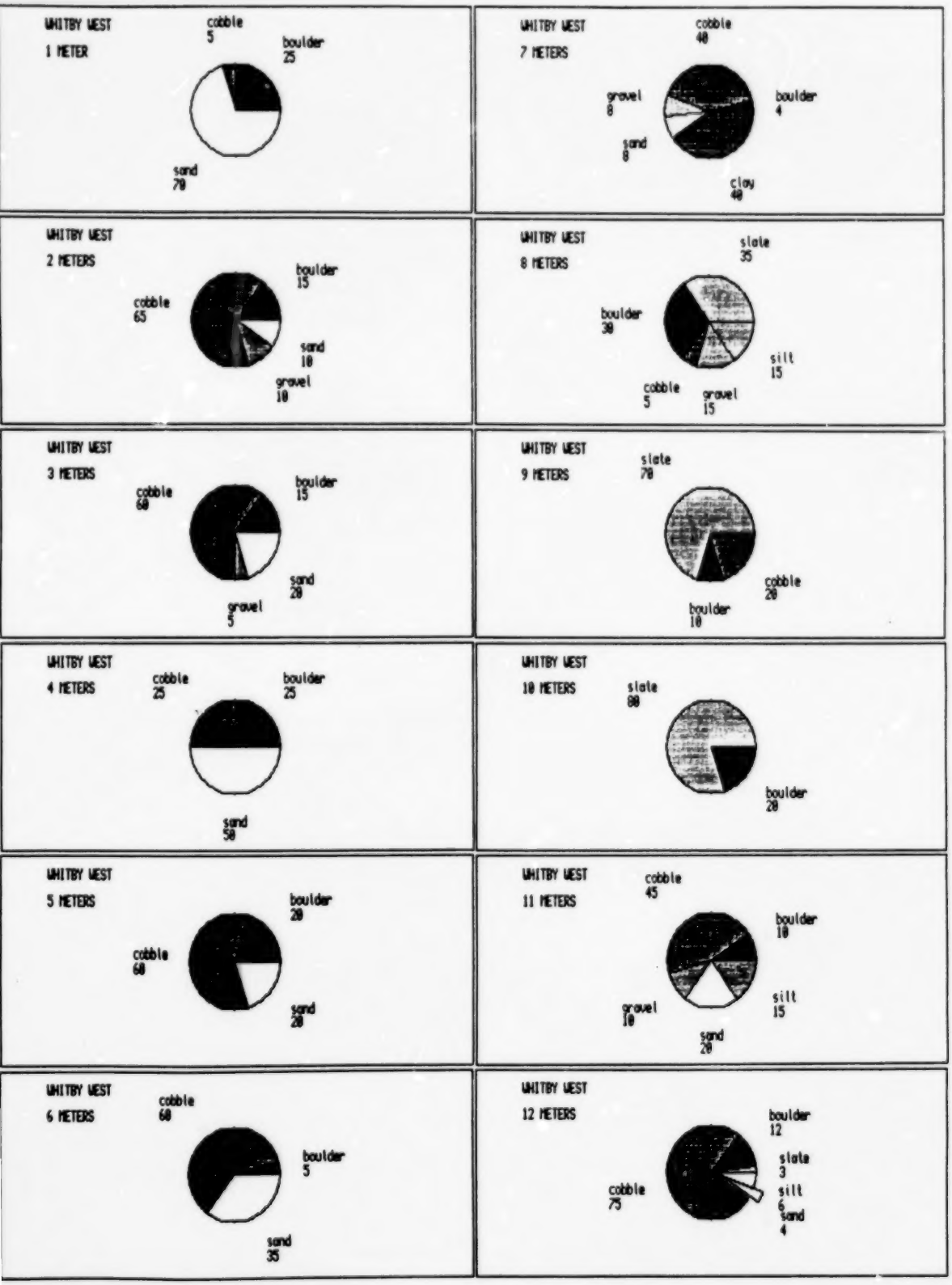
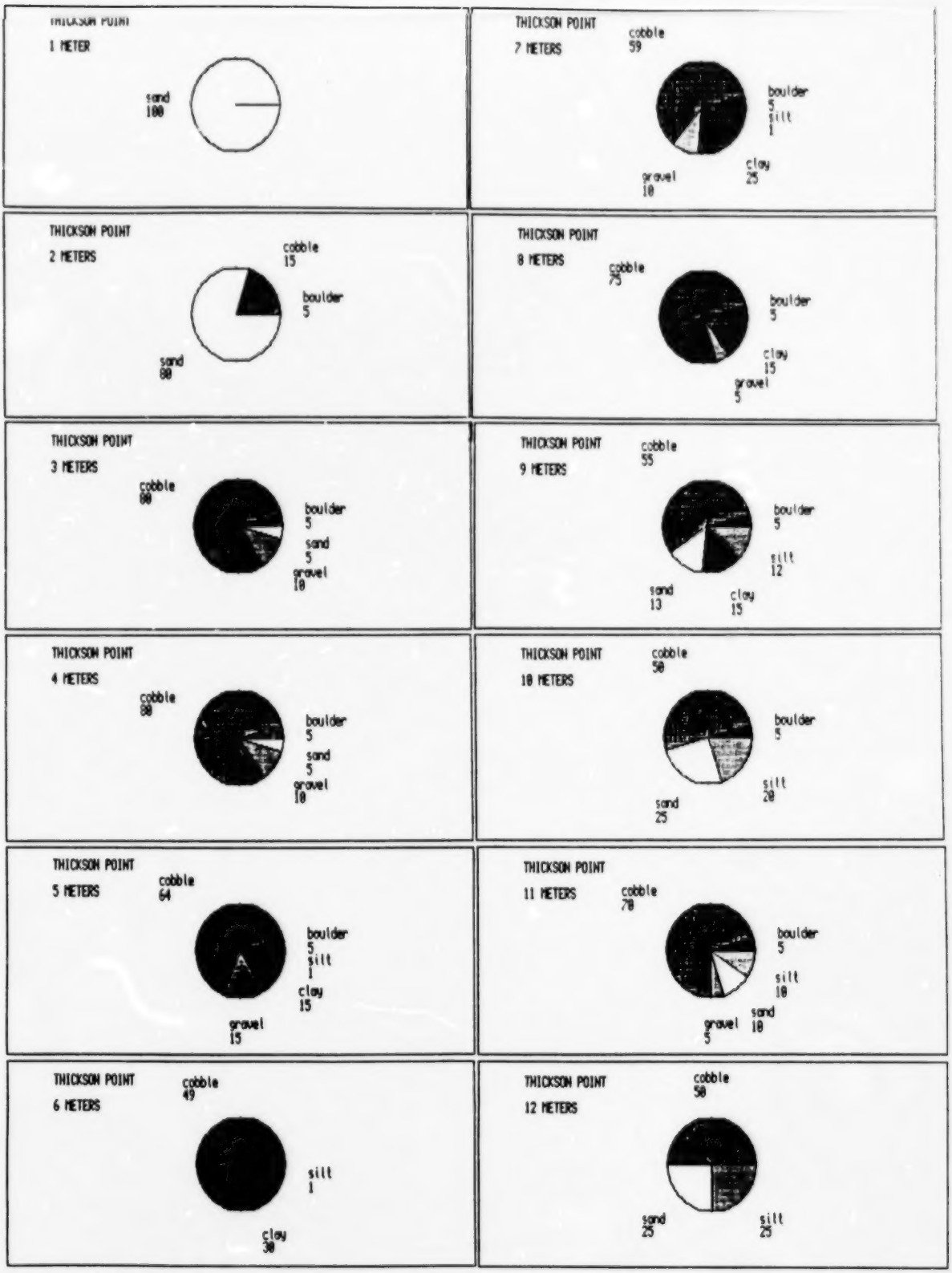


FIGURE 9: THICKSON POINT SUBSTRATE COMPOSITION (ESTIMATED BY DIVERS)



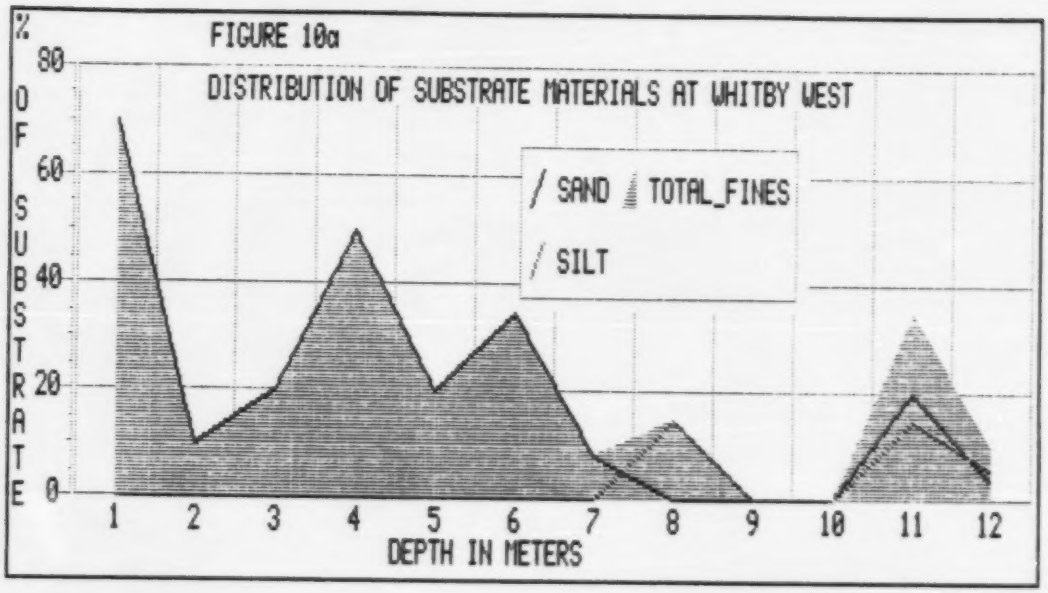


FIGURE 10a
DISTRIBUTION OF SUBSTRATE MATERIALS AT WHITBY WEST
% OF SUBSTRATE
80
60
40
20
0
SAND
TOTAL_FINES
SILT
1 2 3 4 5 6 7 8 9 10 11 12
DEPTH IN METERS

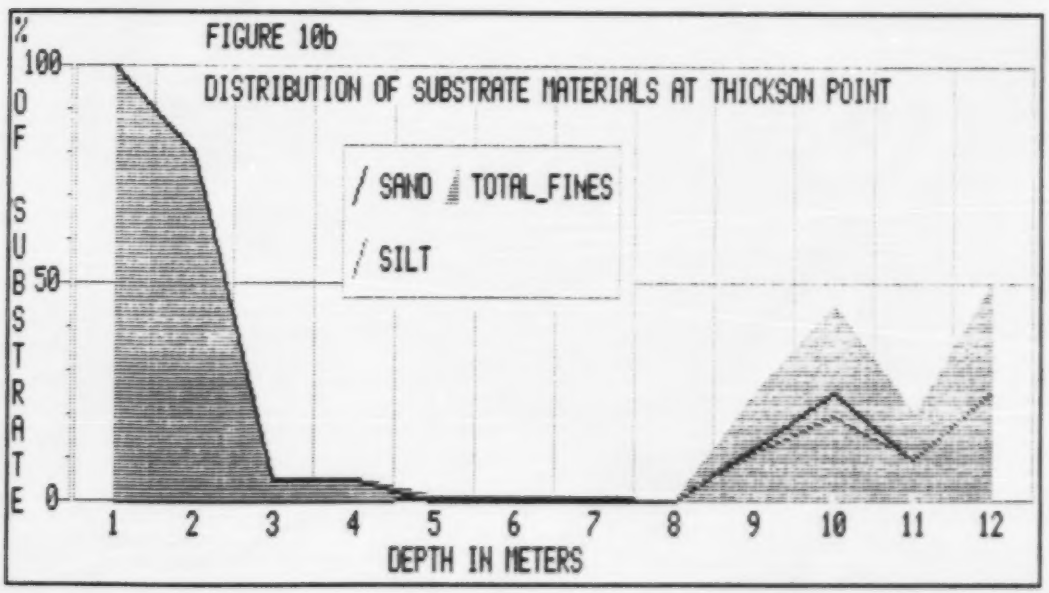


FIGURE 10b
DISTRIBUTION OF SUBSTRATE MATERIALS AT THICKSON POINT
% OF SUBSTRATE
100
50
0
SAND
TOTAL_FINES
SILT
1 2 3 4 5 6 7 8 9 10 11 12
DEPTH IN METERS

likely to be successful at 2 m, 3 m, 5 m, and the 7 m to 10 m range. In the nearshore zone (less than 7 meters) the fine sediments are mostly sand, whereas silt is more abundant at 8 meters, 11 meters and 12 meters.

The plot for Thickson Point (Figure 10B) indicates a substantial abundance of sand at 1 m and 2 m depths, with sand and silt at equivalent abundances over the 9 to 12 meter range. The plot suggests that spawning would be most successful over the 3 meter to 8 meter little fine grained sediment was observed at these depths. In general, Figure 10 suggests that the Thickson Point site may be more suitable than the Whitby West site for round whitefish spawning due to the smaller amount of fine materials present.

The substrate photographs were also used to provide estimates of spawning suitability for the Whitby West and Thickson Point substrates. At each depth (from 1 meter to 12 meters) three substrate photographs were taken. The camera was mounted on an aluminum support frame about 60 cm above the bottom. The area covered by each photo was about 38 cm x 55 cm. The 35 mm substrate slides were examined on a slide viewer and rated according to their suitability as spawning sites. A numerical rating scale (from 0 to 10) was used to rate the photos (Appendix 4A). In this rating scheme (developed by the author), the most suitable substrates (given a rating of 10) were clean cobble or boulder beds with many layers, which would allow eggs to freely settle some distance into the substrate for protection (from waves or predators), but would not restrict water movement over the eggs. Substrates of this type have been observed by the author at Bruce NGS on Lake Huron, but generally the Lake Ontario substrates contain some fines between the stones which may reduce the depth to which eggs will settle into the substrate. Accordingly, the 'best' substrates observed in the Pickering photos were given a rating of 7. A rating of 5 was assigned to substrates which were mostly cobble or boulder, with the spaces between stones largely cemented with fine material (sand, clay or silt). These substrates provided only limited spaces for settling eggs and were considered marginally suitable for spawning. A rating of 0 was assigned to those substrates considered entirely unsuitable for spawning (pure sand, silt or very dense Cladophora beds).

The entire sequence of photos from Whitby West and Thickson Point was examined repeatedly over a period of several days, resulting in the ranking listed Appendix 4B. While the ranking system used is recognized as being quite subjective (round whitefish may have a different view of substrate suitability than that of the author), the present method at least allows a semi-quantitative assessment of the substrate photos.

The spawning suitability index is plotted against depth for the Whitby West site in Figure 11A. In this figure, the range between maximum and minimum values (of the three photos) at each depth is shown by the shaded area. The mean value is shown by the dark line. Substrates at the 1 and 2 meter depths were considered poor because of the abundant

sand (1m) and heavy Cladophora growth (2m). Only one photo was available at the 3 m depth, and the substrate appeared quite good (relatively clean boulder/cobble). Substrates at 4 meters appeared to be quite variable but were considered poor on average due to excessive sand and algal growth. Generally good substrates were observed over the 5 m to 7 m depth range. Substrates were largely boulder/cobble with a moderate amount of sand between the stones. Substrates appeared less suitable at 8 and 9meters. Here slate slabs, boulders and cobble were embedded in a layer of sand. A thin layer of silt also covered the substrate. At 10 meters, all 3 photos indicated good spawning potential. The substrate was mostly slate slabs piled randomly, providing protected spaces for settlement of eggs. Substrates at 11 and 12 meters were generally poor, consisting of boulder, cobble and gravel embedded in a layer of silty sand. The stones were also covered by a substantial layer of silt.

Photographs taken at Thickson Point indicated that substrates in the 1 to 2 meter range were unsuitable for spawning due to the abundance of sand (Figure 11B). Over the 3 m to 5 m range, conditions improved substantially as the amount of sand decreased. Spawning potential was considered quite good in the 4 to 5 m range, where relatively clean cobble was piled several layers deep. Some photos at 6 and 7 meters also showed good potential, while other areas of hardpan clay or cobble embedded in clay appeared to offer little protection for developing eggs. Spawning potential appeared to decline over the 8 to 10 m range. Substrates consisted of boulder or cobble in clay or silt, with a progressively thicker covering of silt on the rocks. Potentially better substrates, consisting of cobble/boulder piles with a small amount of silt, occurred at 11 meters. At 12 meters, substrates were rated as very poor, due to abundant silt and sand.

In summary, the substrate photographs have indicated that some potentially good spawning substrates exist at both sites over the depth range (3 to 7 meters) at which larval whitefish have been captured. Shallow substrates (1 to 2 meters) are too sandy or Cladophora covered to be considered suitable for egg incubation, and probably are too exposed to wave action as well. Increasing amounts of clay, silt and sand with increasing depth generally result in poor substrates at depths beyond 7 meters, although considerable variability was observed. Also, a second maximum in substrate suitability was observed in deeper water at both sites (10 m at Whitby West, 11 m at Thickson Point). Larval whitefish were not collected in samples from these depths (9, 12, 15 m sampled).

While results of the substrate photo analysis are in general agreement with diver observations, the photos clearly demonstrated that substrates at both sites are extremely heterogeneous. Thus, while the photos suggest that more good substrates (rated at 7 here) were found at Thickson Point (4 to 7 meter depth range, compared with 6 to 7 meters at Whitby West), the high variability in substrate composition does not allow a clear distinction between the two sites. The extreme heterogeneity of substrates in the region suggests that it is unlikely

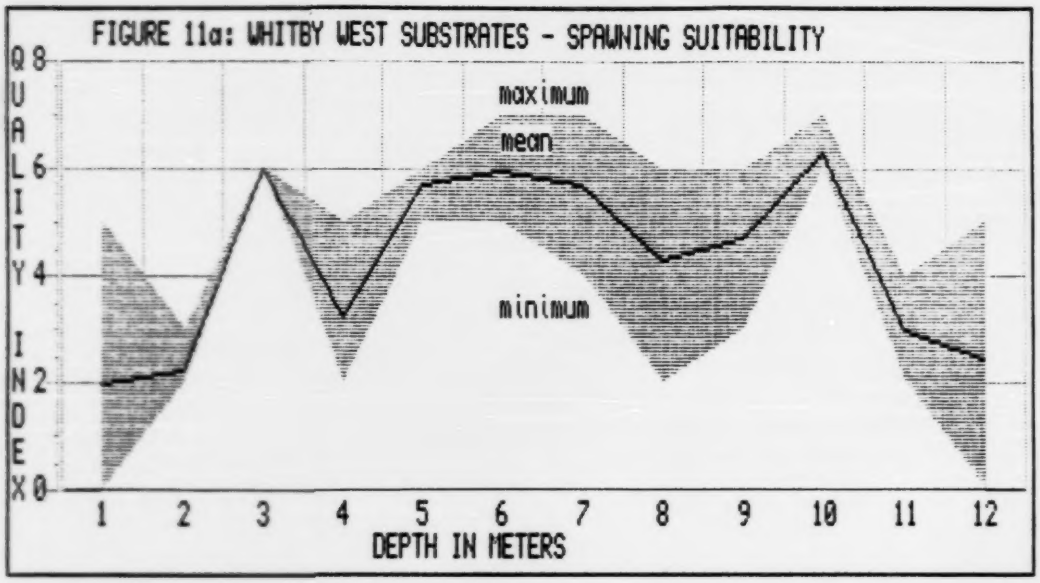


FIGURE 11a: WHITBY WEST SUBSTRATES - SPAWNING SUITABILITY
QUALITY INDEX
0
2
4
6
8
maximum
mean
minimum
1
2
3
4
5
6
7
8
9
10
11
12
DEPTH IN METERS

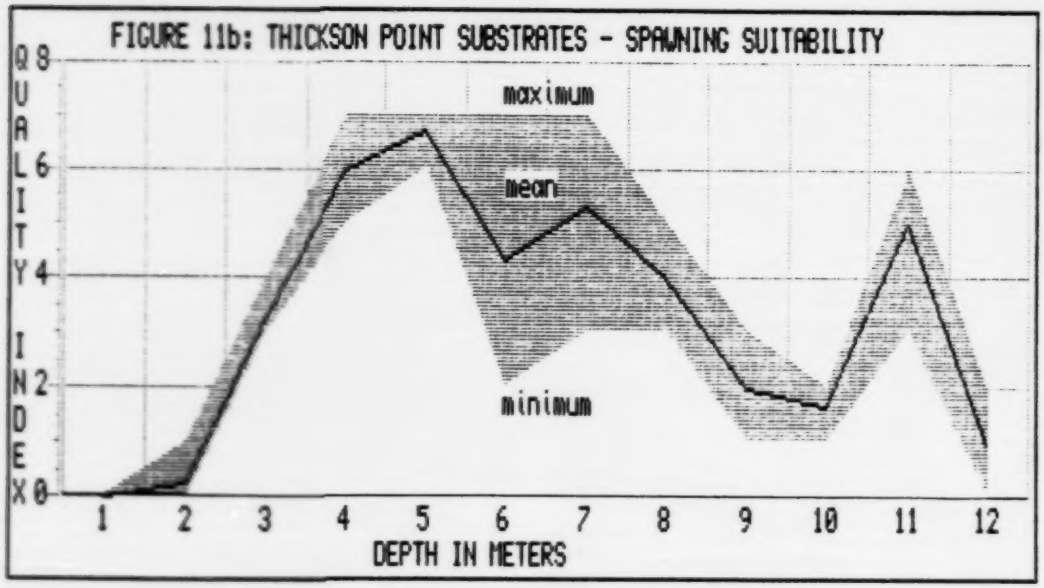


FIGURE 11b: THICKSON POINT SUBSTRATES - SPAWNING SUITABILITY
QUALITY INDEX
0
2
4
6
8
maximum
mean
minimum
1
2
3
4
5
6
7
8
9
10
11
12
DEPTH IN METERS

for a clearly defined 'spawning shoal' to exist. Eggs may be simply broadcast over the area, probably mostly in the 4 to 7 meter depth range. Alternatively, if the fish do select specific spawning substrates, spawning may occur over a number of small 'pockets' of suitable substrates, generally located in this 4 to 7 meter depth range.

3.4 Round Whitefish Egg Incubation Experiment

Results from the field incubators are listed in Appendix 5. Bottom water temperatures obtained from thermographs located at each incubation site (used for simulation studies here) have been reported in Design and Development Division Report No 86093.

Development rate data obtained from the field incubators are plotted in Figure 12. Results indicated very similar rates of development for eggs incubated at Thickson Point and the Rouge River (Figure 12a). These sites, at the extreme east and west ends of the study area, are assumed to be 'control' locations which would be little affected by the thermal discharges from Pickering. A comparison of weekly mean temperatures (Figure 13) suggests that Rouge River temperatures were generally within 1 C° of those at Thickson Point, and that no consistent difference existed between temperatures at these sites over the total incubation period. A positive difference (higher Rouge River temperatures), approximating 0.5 to 0.8 C° over the last 4 weeks of incubation may be indicative of a westerly moving Pickering plume at this time, or may reflect local warming from spring freshets in the Rouge River. This period of warmer temperatures is likely the cause of slightly faster development of the Rouge River fish late in development, resulting in a hatch advancement of approximately one week (Figure 12a). During the 1979-1980 Pickering Winter Plume Study (OH D&D Division Report 81263) warmer temperatures were also noted at this site late in the incubation period.

Eggs at Richardson Point and Simcoe Point developed more rapidly than those at Thickson Point (Figure 12b). Both sites displayed approximately a two week hatch advancement, relative to Thickson Point. Both sites exhibited a consistent, positive temperature rise (relative to Thickson Point) of about 1 C° (Figure 13a). However, Simcoe Point temperatures appeared to be slightly warmer early in incubation (weeks 4 to 9), while Richardson Point temperatures were higher late in development. These differences appear to be reflected in the developmental rates shown in Figure 12b.

Eggs at the Pickering 'B' 7 meter site showed a substantially more rapid rate of development than those at Thickson Point during much of the incubation period, but the difference appeared to be eroded late in development, resulting in a 1 to 2 week advancement at hatch (Figure 12c). During the first six weeks of development, temperatures at the Pickering 7 meter site averaged 1 C° above those at Thickson Point (Figure 13b). From week 7 to week 16, the temperature rise ranged from 0 to 1 C° (mean approximately 0.5 C°) and during the last 3 weeks of incubation, the Pickering 7 meter temperatures were about 0.5 C°

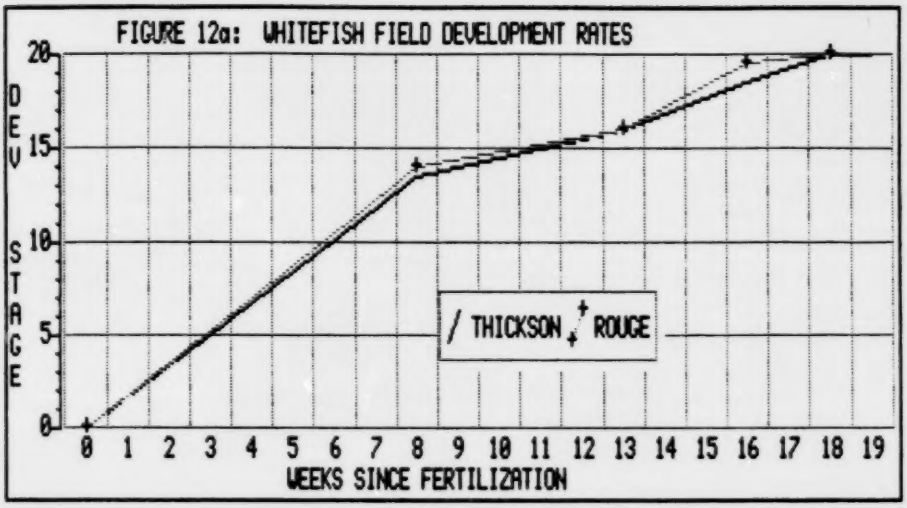


FIGURE 12a: WHITEFISH FIELD DEVELOPMENT RATES
DEV STAGE
0 5 10 15 20
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION
THICKSON
ROUGE

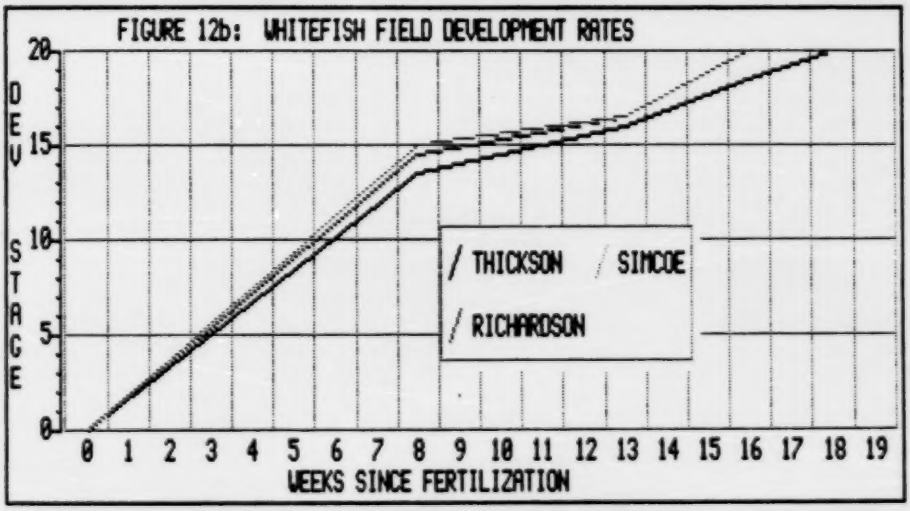


FIGURE 12b: WHITEFISH FIELD DEVELOPMENT RATES
DEV STAGE
0 5 10 15 20
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION
THICKSON
SIMCOE
RICHARDSON

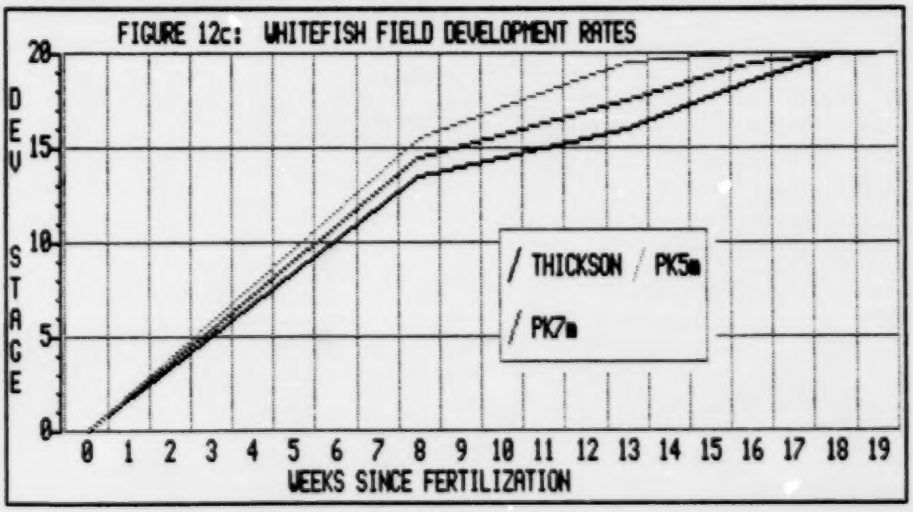


FIGURE 12c: WHITEFISH FIELD DEVELOPMENT RATES
DEV STAGE
0 5 10 15 20
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION
THICKSON
PK5m
PK7m

below those at Thickson Point. Again, these temperature differences appear to be reflected in the development data in Figure 12c.

The most rapid development was observed at the Pickering 'B' 5 meter site (Figure 12c). At week 13, Thickson Point eggs had reached developmental stage 16, the level attained by Pickering 5 meter eggs on week 8. This 5 week advancement appears to have been eroded somewhat in later development, as advancement at hatch approximated 3 weeks. However, the data in Appendix 5 F indicate that by week 16, all eggs in the Pickering 5 m chambers had been hatched for some time, as few larvae were found. Thus, the true time of hatch fell between the week 13 sampling period (when hatch was just beginning) and the week 16 sampling period. Assuming that most hatching occurred on week 14 or 15, a hatch advancement of 4 to 5 weeks results. The largest temperature elevation was observed for the Pickering 'B' 5 meter site (Figure 13b). Weekly mean temperature elevations ranged from 0.5 C° to 4.5 C° during the incubation period, averaging about 3 C° during much of the time.

Thermograph temperatures were used with the laboratory models to predict development rates for each incubator. These predictions are compared with observed results in Figure 14. In general, there is a reasonable correspondence between observed and predicted development. At the time of the first field sampling (week 8), observed development ranged from 1 to 2 stages ahead of the predicted values. The major exception occurred at the Pickering 5 meter site (Figure 14e), where observed development was about 3 stages behind the predicted value. At the time of the second field sampling (week 13), predicted development was from 1 to 3 stages ahead of observed values. By the time of the third sampling (week 16), observed and predicted values closely coincided. Hatch was beginning (stage 19-20) in most incubators at this time, although eggs at the Pickering 5 m site (Figure 14e) had completed hatch.

Although predicted dates for the beginning of hatch (after stage 19) are in good agreement with observed results, the observed duration of the hatching period was considerably shorter than predicted. It was suggested in laboratory studies of lake whitefish and round whitefish (OHRD Reports 79-521-K, 80-140-K) that the duration of the hatching period for these species may be substantially shortened if the eggs are subjected to mechanical agitation (wave action, etc) after stage 19. As the laboratory models were based on eggs which were given minimal agitation, the predicted hatch durations are the longest reported in the literature.

Based on the results shown in Figure 14, comparisons were made between observed and predicted dates for the beginning of hatch (stage 19), 50% hatch (stage 19.5) and completion of hatch (stage 20). The comparison (using all six sites) indicated that the predicted date for beginning of hatch was underestimated by an average of 1.17 weeks (8.2 days), with a range of -3.5 weeks to +0.5 weeks). The date for 50% completion of hatch was overestimated by 0.33 weeks (2.3 days), with a range of -1.5 weeks to +1.5 weeks. The date for completion of hatch was overestimated by an average of 1.67 weeks (11.7 days), with a range from -1 weeks to

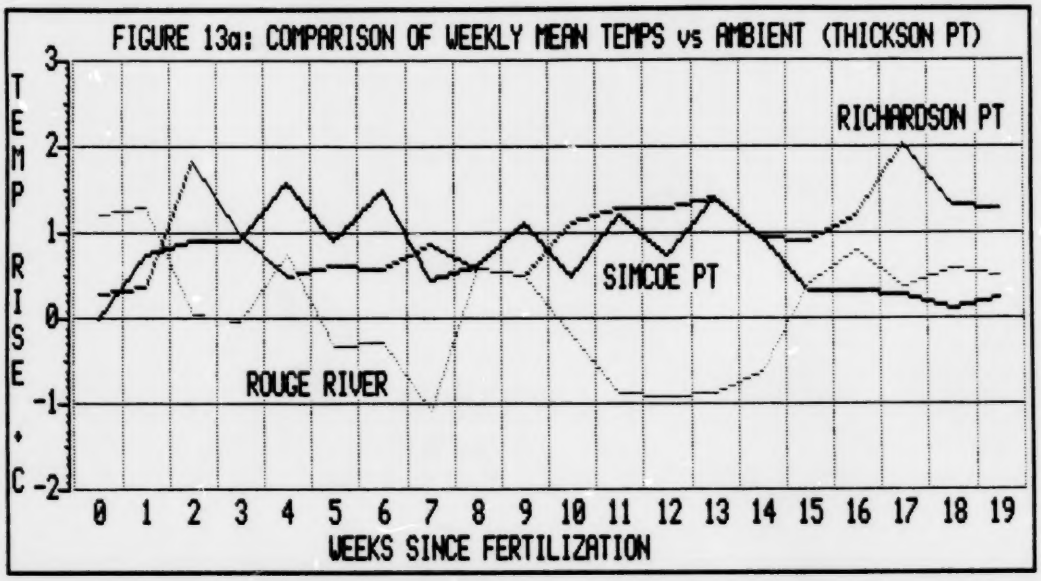


FIGURE 13a: COMPARISON OF WEEKLY MEAN TEMPS vs AMBIENT (THICKSON PT)
TEMP RISE °C
3
2
1
0
-1
-2
RICHARDSON PT
SIMCOE PT
ROUGE RIVER
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

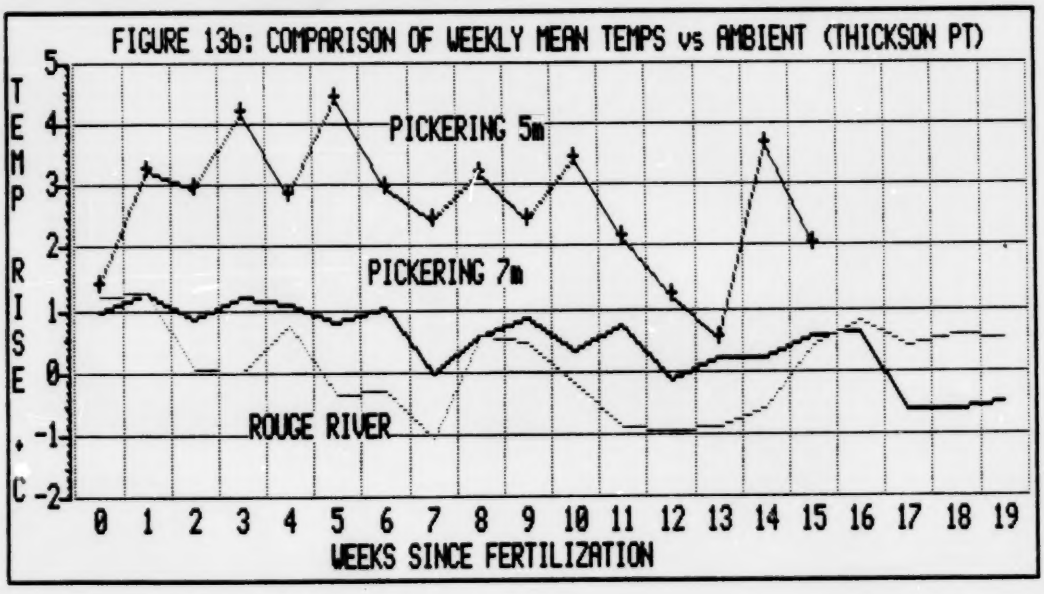


FIGURE 13b: COMPARISON OF WEEKLY MEAN TEMPS vs AMBIENT (THICKSON PT)
TEMP RISE °C
5
4
3
2
1
0
-1
-2
PICKERING 5m
PICKERING 7m
ROUGE RIVER
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

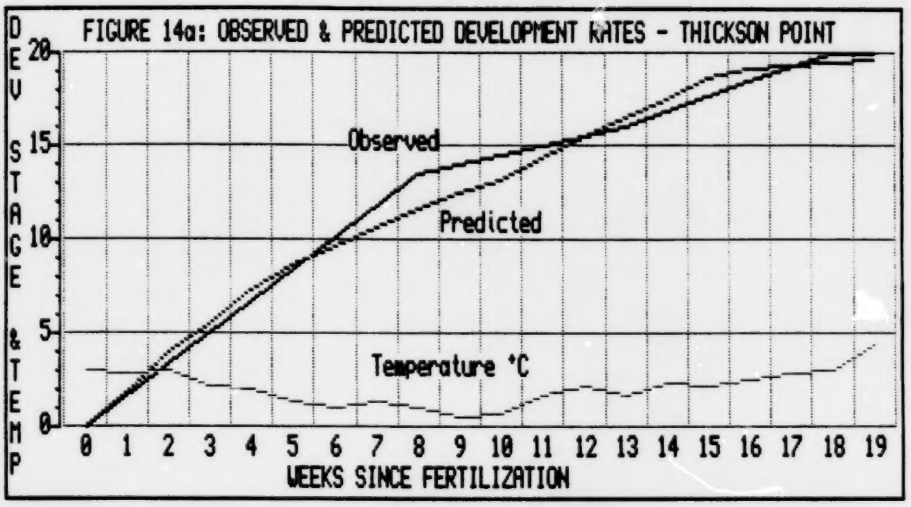


FIGURE 14a: OBSERVED & PREDICTED DEVELOPMENT RATES - THICKSON POINT
DEV STAGE & TEMP
20
15
10
5
0
Observed
Predicted
Temperature °C
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

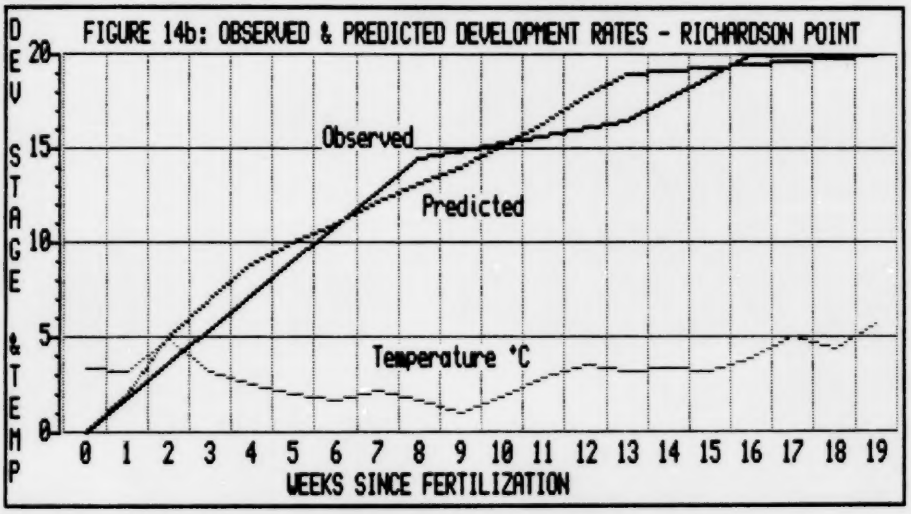


FIGURE 14b: OBSERVED & PREDICTED DEVELOPMENT RATES - RICHARDSON POINT
DEV STAGE & TEMP
20
15
10
5
0
Observed
Predicted
Temperature °C
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

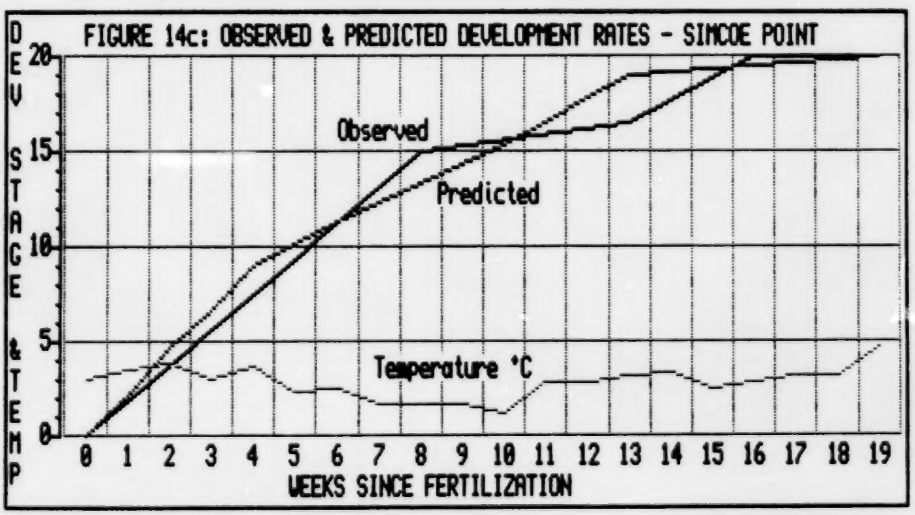


FIGURE 14c: OBSERVED & PREDICTED DEVELOPMENT RATES - SIMCOE POINT
DEV STAGE & TEMP
20
15
10
5
0
Observed
Predicted
Temperature °C
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

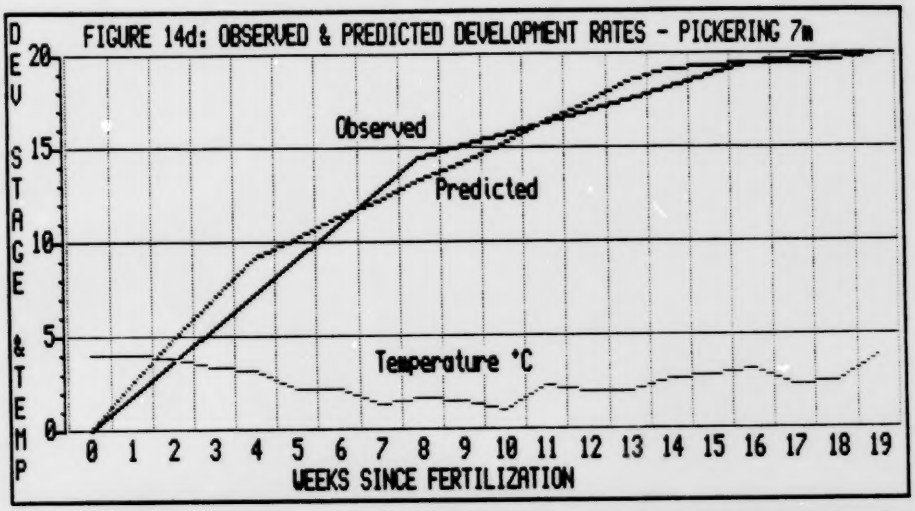


FIGURE 14d: OBSERVED & PREDICTED DEVELOPMENT RATES - PICKERING 7m
DEV STAGE & TEMP
Observed
Predicted
Temperature °C
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

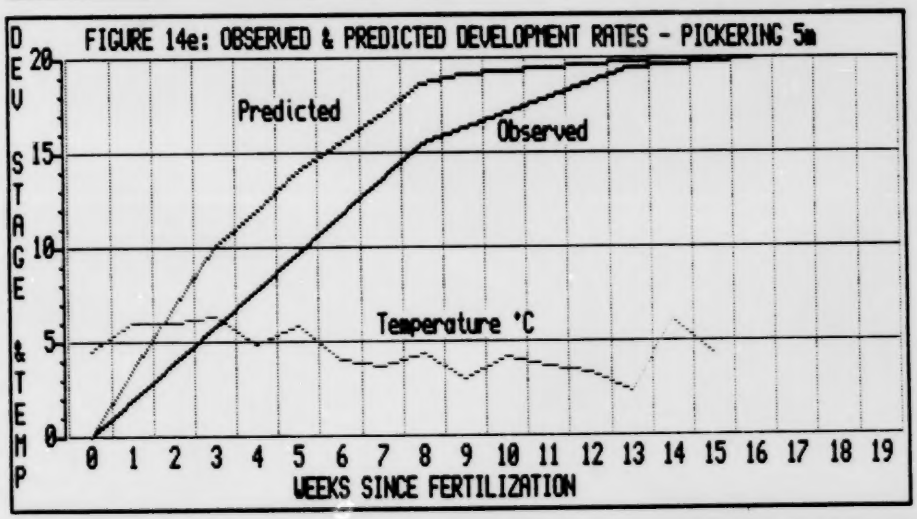


FIGURE 14e: OBSERVED & PREDICTED DEVELOPMENT RATES - PICKERING 5m
DEV STAGE & TEMP
Predicted
Observed
Temperature °C
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

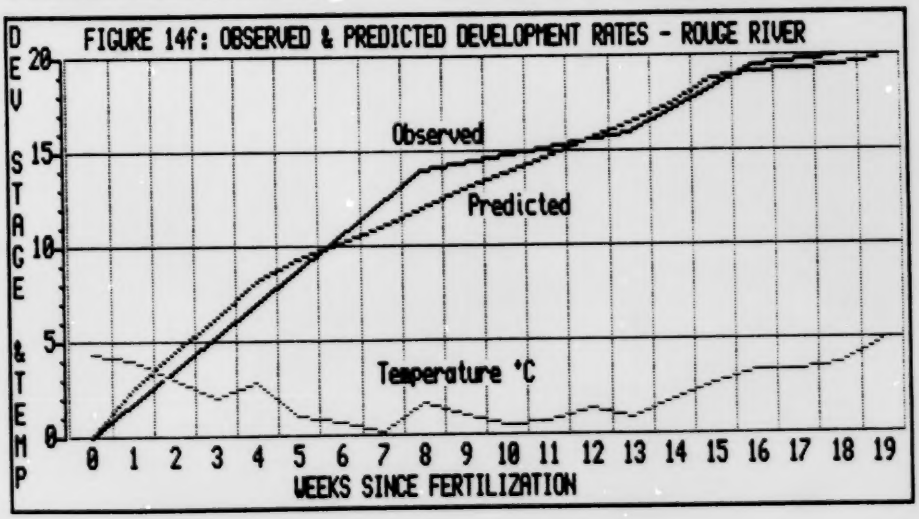


FIGURE 14f: OBSERVED & PREDICTED DEVELOPMENT RATES - ROUGE RIVER
DEV STAGE & TEMP
Observed
Predicted
Temperature °C
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

+3 weeks). Thus, the results strongly indicate that the predicted date for 50% completion of Block 3 (stage 19.5, or approximately median hatch) would be a good estimator of field hatching times.

From the results in Appendix 5, it is apparent that some difficulty exists in precisely defining the percentage hatch success, as most larvae died shortly after hatch (note the high percentage of dead larvae in all incubators). It is likely that slit accumulation on the chamber screens and on the gravel within the incubators was the major cause of this mortality. It is believed that in natural substrates (without the confinement of fine-mesh screens), most larvae which hatched would survive to emerge from the gravel. Thus, data collected from the final chamber recovery (April 26) cannot be used to estimate the hatch success. Probably the best indicator of hatch success is the survival percentage during the early portion of the hatching process. Most incubators were sampled at about this time. While some unhatched eggs would not survive hatching, this error would be somewhat offset by the mortality of some of the larvae which had already hatched. In Figure 15, mean survival rates are plotted against development time (weeks) for each of the incubators. The last dates included in the plot are generally those where hatch had begun, but a substantial number of live eggs remained unhatched.

Results (Figure 15a) indicate very similar rates of survival for eggs incubated at the most easterly points (Thickson, Richardson, Simcoe). Although unusually high survival was observed for the Thickson Point samples taken on week 16, the data generally show a consistent decline in survival over the incubation period. The average survival observed at week 18 for the Thickson Point samples (32%) is probably an underestimate of the survival at hatch for this location, as almost all eggs had hatched by this time, and a substantial number of dead larvae were present (Appendix 5a). It is suggested that the actual hatch success at Thickson Point was probably comparable to the values shown for Richardson Point and Simcoe Point at week 16 (approximately 41%). If the dead larvae observed at Thickson Point are included in the hatch estimate, the average hatch for Thickson Point would be 43.7%. Thus, assumption of an average hatch of 41% for all three sites in Figure 15a appears reasonable.

Much lower survival rates were observed at the two Pickering 'B' sites and the Rouge River site (compare with Thickson Point results in Figure 15b). At week 8, survivals at these sites ranged from 36 to 46%, while the Thickson Point survival exceeded 70% at this time. Survival continued to decline at the Pickering 5 meter site, approximating 22% when the chambers were sampled on week 13. At this time, hatch had just begun at the Pickering 5 m site. The 22% value is probably a reasonable maximum estimate of the hatch success, as on the subsequent sampling period (week 16), no live unhatched eggs were present (Appendix 5E). The percentage hatch success cannot be clearly estimated from the Pickering 7 meter results. Survivals at week 8 (41%) and week 13 (33%) closely approximated the Pickering 5 m and Rouge River results, but

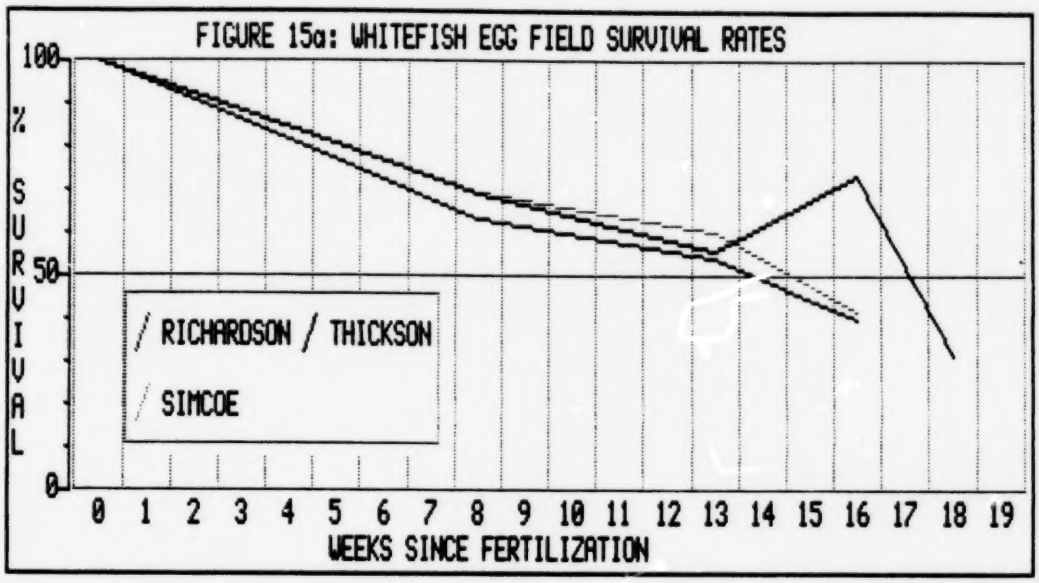


FIGURE 15a: WHITEFISH EGG FIELD SURVIVAL RATES
100
%
SURVIVAL
50
0
/ RICHARDSON / THICKSON
/ SIMCOE
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

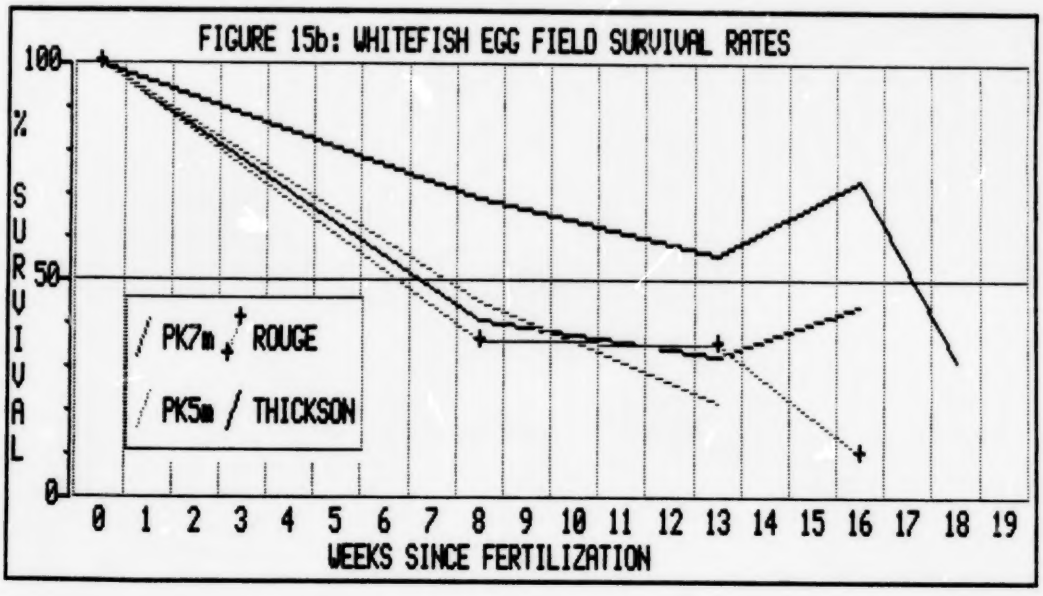


FIGURE 15b: WHITEFISH EGG FIELD SURVIVAL RATES
100
%
SURVIVAL
50
0
/ PK7m / ROUGE
/ PK5m / THICKSON
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

higher survival (44%) was observed on week 16, when hatch was just beginning. By week 18, hatch was complete, and most hatched larvae had died (Appendix 5D). Only 6% survival was noted at this time. Survival of eggs at the Rouge River site was low, approximating that at the Pickering sites (Figure 15b). When the eggs were sampled on week 16, hatch was just beginning and the survival percentage at that time (11%) is probably a reasonable estimate of the maximum hatch. Total numbers of larvae (both live and dead) in subsequent samples suggest that total hatch did not exceed about 10% (Appendix 5F).

The thermograph records were used with the laboratory models to predict survival rates for each incubation site. The results (Figure 16) indicate that predicted survivals were substantially higher than observed survivals at all sites. However, the predictions do indicate that the thermal regimes were sufficiently different to significantly alter survival. Best survival (87%) was predicted for the Thickson Point site, with somewhat lower values predicted for Simcoe and Richardson Points (Figure 16a). Of these three locations, the lowest predicted survival was for Richardson Point, a result which agrees with observed data. The predictions suggest that warm temperatures during sensitive early and late developmental stages (see Figure 13a, week 2 and weeks 16 to 19) were the cause of this decrease in predicted survival (to 80%).

Temperature elevations at the Pickering 5 m site were sufficient to reduce predicted survival to 66% (Figure 16b). However, this was not the case at the Pickering 7 m site, where predicted survival was only slightly lower than the Thickson Point value. Predicted survival at the Rouge River site (Figure 16c) was also only slightly lower than that at Thickson Point during much of the incubation period. Increasing temperatures late in development resulted in a sharp decline in predicted survival (to 81%) at this location.

While the predicted survivals are in general agreement with observed results (best survival at Thickson Point, lowest at Pickering 5 m site), the relatively low survivals obtained at the Pickering 7 m and Rouge River sites were not predicted and do not appear to be the result of thermal effects. It is suggested that wave damage and silation are two factors which may have reduced observed survivals from predicted levels. All incubation sites were located on open, exposed shorelines, and would likely be subjected to similar wave forces. By the end of the experiment, most incubators showed some evidence of wave damage, as some of the gravel surrounding the egg cages had been washed out of the containment structure.

All egg chambers also accumulated fine sediments (silt, sand) on the screens and within the gravel substrate. These fines may have impaired water exchange and increased egg mortality (as well as contributing to post-hatch death of larvae). When the egg chambers were examined, it was apparent that the greatest amount of sediment accumulation consistently occurred in the egg chambers at the Rouge River and Pickering sites, while the eggs and incubation chambers at Thickson

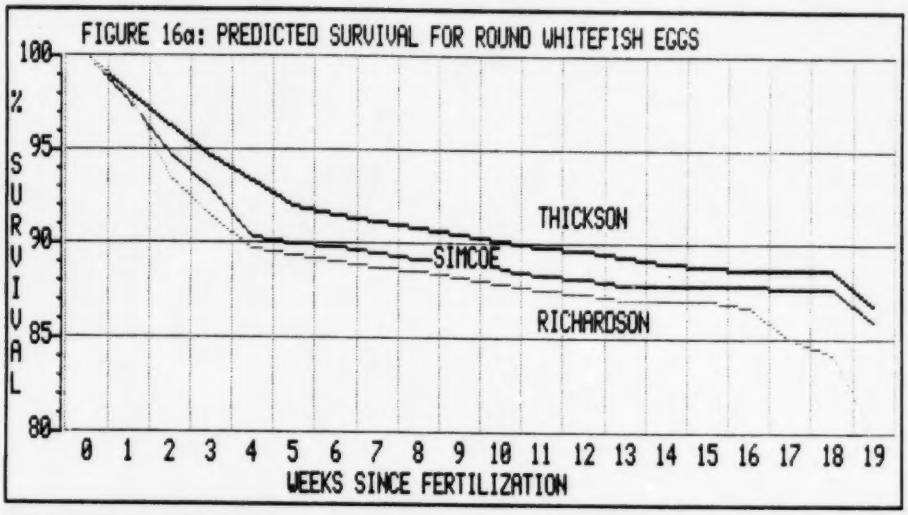


FIGURE 16a: PREDICTED SURVIVAL FOR ROUND WHITEFISH EGGS
% SURVIVAL
100
95
90
85
80
THICKSON
SIMCOE
RICHARDSON
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

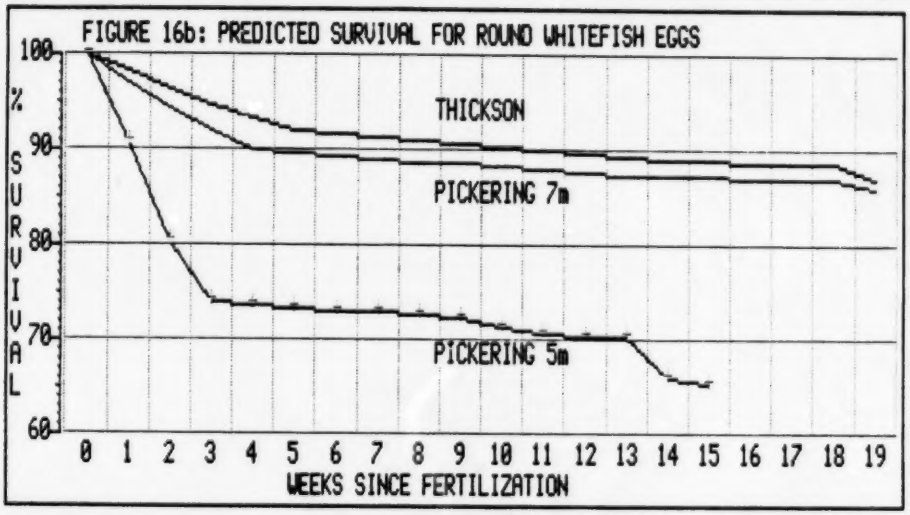


FIGURE 16b: PREDICTED SURVIVAL FOR ROUND WHITEFISH EGGS
% SURVIVAL
100
90
80
70
60
THICKSON
PICKERING 7m
PICKERING 5m
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

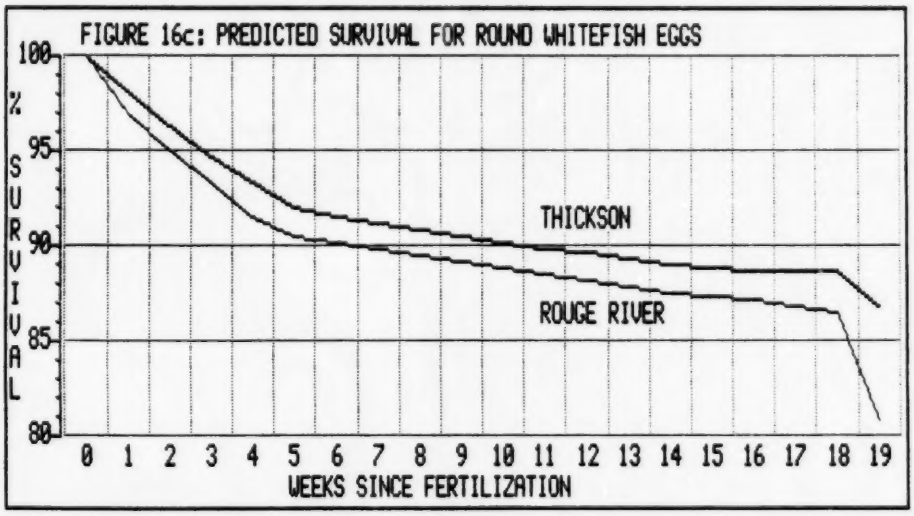


FIGURE 16c: PREDICTED SURVIVAL FOR ROUND WHITEFISH EGGS
% SURVIVAL
100
95
90
85
80
THICKSON
ROUGE RIVER
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WEEKS SINCE FERTILIZATION

Point were consistently the cleanest. Quantitative measurements of sediment accumulation were not made. Turbidity data obtained at the times of egg recovery are incomplete, and during the latter stages of egg development, consisted only of the diver's visibility estimates (Appendix 5). However, these data do suggest that the highest turbidity measurements and the lowest underwater visibility were associated with the Rouge River and Pickering locations. Thus, it seems reasonable to assume that sedimentation had a proportionally greater adverse effect on eggs at the Rouge River and Pickering sites than at locations east of Pickering. At the Rouge River site, sediment accumulation in the egg chambers was especially severe.

4.0 SUMMARY

1. Round whitefish was the most abundant species caught (97 fish) in 16 gillnet sets during late November and December, 1984. The average catch (CUE = 6.06 fish/net) was higher than in previous years. As in previous studies, largest catches were obtained at the Thickson Point site, but the average CUE was not significantly higher than at Whitby West. Round whitefish were more abundant at the 7 meter depth than at the 3 meter depth, a significant difference when 1982-85 catch data were considered.

2. Comparison of age structure for round whitefish captured at Pickering over the 1979-1985 period with fish captured at Darlington over the 1976-1984 period suggests differences in age structure. The age of peak abundance was 4+ for Pickering fish and 5+ for Darlington fish. The Pickering samples were also characterized by a greater average abundance of fish aged 2+ and 3+, while older fish (5+, 6+) were more common in Darlington samples. However, high variability resulting from some exceptionally strong year classes prevented these apparent differences from attaining statistical significance. If these apparent differences are real, separate stocks of round whitefish may be spawning at Pickering and Darlington. However, growth rates for the two groups were similar.

3. Review of round whitefish age structure data indicated that the 1977 year class was exceptionally strong, both at Pickering and Darlington. This strong year class appears to be associated with unusually cold temperatures during the winter of 1976-77. In addition to directly improving survival of incubating eggs, cold weather may improve survival through development of a protective nearshore ice-pack and reduce turbidity and wave damage along the north shore at Lake Ontario due to increased frequency of northerly winds. Computer simulations of thermal discharge effects have indicated that small temperature increases (2 C°) would have little effect on egg survival during cold winters, but could substantially reduce survival during warm winters.

4. In 1984, six round whitefish larvae were collected from 108 benthic sled samples which filtered approximately 6400 m^3 of lakewater. A similar effort in 1985 (96 samples) also captured six larvae. Computations based on the theoretical minimum number of spawners at Pickering suggested that sled capture efficiencies were less than 3.5%, a value which agrees with observed captures of round whitefish larvae by a scale model sled towed over a cobble substrate in a test flume. Although few larvae were captured in the field, results suggest some spawning at both the Whitby West and Thickson Point sites, at depths between 3 and 7 meters.

5. Bottom substrates from 1 to 12 m depth at Whitby West and Thickson Point were evaluated for spawning suitability from diver observations and a series of substrate photographs. Diver observations suggested that spawning would be most successful over the 3 to 8 m depth range, and that the Thickson Point site may be the more suitable due to the smaller amount of fine materials (sand, silt) present. The substrate photos (3 per depth) were in general agreement with the diver observations, but clearly demonstrated the heterogeneous nature of the substrates. Also, the photos suggested that some suitable substrate exists at greater depths (10-11 meters), where whitefish larvae were not captured.

6. Development rate data from round whitefish eggs incubated at 6 sites indicated a maximum advancement of hatch (relative to Thickson Point) of 4 to 5 weeks in the immediate vicinity of the Pickering 'B' discharge (5 meter site). The temperature rise averaged about 3 C° at this site, although weekly average elevations of up to 4.5 C° were observed. Hatch advancement approximated two weeks at Richardson and Simcoe Points (temperature rise about 1 C°) and one week at the Rouge River and Pickering 7 meter sites (temperature rise about 0.5 C°). Computer simulations run using thermograph temperatures from the incubation sites were in general agreement with observed results, although some discrepancies were noted. The simulations indicated that the predicted date for 50% completion of hatch would be a good estimator of field hatching times. The average difference between this predicted date and the observed field hatch date was 2.3 days, with a range (for the 6 incubation sites) of -10 days to +10 days.

7. Best survival (approximately 41%) was obtained from eggs incubated at Thickson Point, Richardson Point and Simcoe Point. Survivals were lower at the Pickering and Rouge River sites. Due to sampling variability and the timing of sampling, the survival at hatch was not clearly defined for the Pickering 7 m site. Survival at hatch approximated 22% at the Pickering 5 m site and 11% at the Rouge River site. Simulations run using the daily thermograph temperatures indicated that predicted survivals were higher than observed values at all sites, but the temperature

elevations were sufficient to account for a substantial portion of the mortality observed at the Pickering 3 m site. The low survivals observed at the Rouge River and Pickering 7 m sites were not predicted and do not appear to be the result of thermal effects. It is suggested that turbidity and sediment accumulation in the incubation chambers had a proportionally greater adverse effect at the Rouge River and Pickering sites than at the locations east of Pickering (Thickson, Richardson, Simcoe). Sediment accumulation in the egg chambers was especially severe at the Rouge River site.

ACKNOWLEDGMENTS

This study was planned and initiated by Mr. W.E. Carey. The author wishes to acknowledge his substantial contribution to the project. Thanks are also due to Biological Research divers (E. Checko, L. King, H. Kowalyk, D. Lowther, L. Onisto, O. Turczyn) who successfully recovered egg samples under the most severe winter conditions of freezing temperatures and zero visibility. The manuscript was reviewed by J. Maher and G. Pope of Environmental Studies and Assessments.

Approved:

M. Booth
Manager (Acting)
Chemical Research Dept

Prepared:

J.S. Griffiths
Biologist
Biological Research Section

Reviewed by:

G.T. Haymes
Supervising Biologist (Act)
Biological Research Section

JSG:km

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APPENDIX 1 A

GILLNET CATCH - NOVEMBER / DECEMBER, 1984

AT WHITBY WEST & THICKSON POINT SITES

	NOVEMBER 20				NOVEMBER 27				DECEMBER 6				DECEMBER 11				
	TP		WW		TP		WW		TP		WW		TP		WW		
SPECIES	3m	7m	3m	7m	3m	7m	3m	7m	3m	7m	3m	7m	3m	7m	3m	7m	TOTAL
Alewife	2		11	3					1								17
White Sucker	8	3	21	5	1	2	1		2			5	8	5		2	63
Lake Trout	6	5	1	5	1	3		1			1	2			3	1	29
Brown Trout	5		7	1	4			1	9		15	1	6	2	4		55
Rainbow Trout			1								1					1	3
Round Whitefish	3	4	1	12	4	7	5	1	7	7	1	2	2	29	5	7	97
Lake Whitefish	3																3
White Bass			2		1		2		5		2			2	1		15
White Perch		1		2		1							1	2	1		8
Yellow Perch	1		5	1	1	1			1						1		11
Brown Bullhead					1												1
Gizzard Shad	4		4	1					1						2		12
NET TOTALS	32	13	53	30	13	14	8	3	26	7	20	10	17	40	17	11	314

APPENDIX 1 B
AGE STRUCTURE DATA FOR ROUND WHITEFISH
CAPTURED AT PICKERING AND DARLINGTON

Location & Year	Age (years +)								
	1	2	3	4	5	6	7	8	9
Pickering 1979									
Number	0	17	9	0	2	11	3	1	0
% of sample	0	39.5	20.9	0	4.7	25.6	7.0	2.3	0
Pickering 1980									
Number	1	6	73	24	36	9	0	0	0
% of sample	0.7	4.0	49.0	16.1	24.2	6.0	0	0	0
Pickering 1981									
Number	0	0	7	19	14	5	7	0	0
% of sample	0	0	13.5	36.5	26.9	9.6	13.5	0	0
Pickering 1982									
Number	7	1	8	28	25	12	2	0	0
% of sample	8.4	1.2	9.6	33.7	30.1	14.5	2.4	0	0
Pickering 1983									
Number	0	7	7	21	17	5	2	0	0
% of sample	0	11.9	11.9	35.6	28.8	8.5	3.4	0	0
Pickering 1984									
Number	1	1	14	18	12	2	1	0	0
% of sample	2.0	2.0	28.6	36.7	24.5	4.1	2.0	0	0
Pickering 1985									
Number	0	7	10	60	27	1	0	0	0
% of sample	0	6.7	9.5	57.1	25.7	0.9	0	0	0
Darlington 1976									
Number	0	0	0	4	4	5	1	0	0
% of sample	0	0	0	28.6	28.6	35.7	7.1	0	0
Darlington 1977									
Number	0	0	2	27	39	16	4	0	0
% of sample	0	0	2.3	30.7	44.3	18.2	4.6	0	0
Darlington 1980									
Number	0	1	24	11	10	1	0	0	0
% of sample	0	2.1	51.1	23.4	21.3	2.1	0	0	0
Darlington 1984									
Number	0	3	26	42	60	42	19	6	2
% of sample	0	1.5	13.0	21.0	30.0	21.0	9.5	3.0	1.0

APPENDIX 1 C
PICKERING ROUND WHITEFISH
SUMMARY OF GROWTH DATA - 1984 & 1985

1984 Age vs Length (cm)	AGE (YEARS +) 1	2	3	4	5	6	7
number	1	1	14	18	12	2	1
mean length	22.3	29.2	33.6	36.5	40.1	39.8	44.5
Std. Dev.	---	---	1.2	2.5	1.6	2.5	---
1985 Age vs Length (cm)							
number	0	7	10	61	27	1	0
mean length	-	26.4	32.9	35.7	38.9	42.5	-
Std. Dev.	-	2.3	2.2	2.6	2.8	---	-
1984 & 1985 Age vs Length							
number	1	8	24	79	39	3	1
mean length	22.3	26.8	33.3	35.9	39.3	40.7	44.5

1984 Age vs Weight (g)	AGE (YEARS +) 1	2	3	4	5	6	7
number	1	1	14	18	12	2	1
mean weight	110	260	399	531	816	710	1050
Std. Dev.	---	---	48	69	150	156	---
1985 Age vs Weight (g)							
number	0	7	10	61	27	1	0
mean weight	-	233	373	534	734	1400	-
Std. Dev.	-	34	82	126	179	---	-
1984 & 1985 Age vs Weight							
number	1	8	24	79	39	3	1
mean weight	110	236	388	533	759	940	1050

APPENDIX 2 A
PICKERING 1984 BENTHIC SLED CATCH DATA

Date	Location	Depth (m)	# Samples	# Whitefish	# Others
April 12	Whitby W	3	4	0	1 sculpin
		5	4	0	0
		7	4	0	0
April 24	Whitby W	3	4	1	0
		5	4	0	0
		7	4	2	0
April 26	Whitby W	3	4	0	0
		5	4	0	0
		7	4	0	1 sculpin
April 11	Thickson	9	4	0	0
April 12	Thickson	12	4	0	0
		15	4	0	4 sculpins
April 17	Thickson	9	4	0	1 sculpin
		12	4	0	1 sculpin
		15	4	0	0
April 18	Thickson	3	4	0	1 sculpin
		5	4	0	1 sculpin
		7	4	0	2 sculpins
		9	4	0	0
		12	4	0	0
		15	4	0	0
April 25	Thickson	3	4	0	0
		5	4	1	2 sculpins
		7	4	2	0
		9	4	0	1 sculpin
		12	4	0	0
		15	4	0	0
	TOTALS		108	6	15 sculpins

APPENDIX 2 B
PICKERING 1985 BENTHIC SLED CATCH DATA

Date	Location	Depth (m)	# Samples	# Whitefish	# Others
April 16	Whitby W	3	4	0	0
		5	4	0	0
		7	4	0	0
April 17	Whitby W	3	2	0	0
		5	2	0	0
		7	2	0	0
		9	2	0	0
		12	2	0	0
		15	2	0	0
April 22	Whitby W	3	2	0	8 smelt
		5	2	0	0 eggs
		7	2	0	0
		9	2	0	0
		12	2	0	0
		15	2	0	0
April 17	Thickson	3	2	0	0
		5	2	0	0
		7	2	0	0
		9	2	0	0
		12	2	0	0
		15	2	0	0
April 19	Thickson	3	2	2	0
		5	2	0	0
		7	2	1	0
		9	2	0	0
		12	2	0	0
		15	2	0	0
April 22	Thickson	3	2	0	0
		5	2	0	0
		7	2	1	0
		9	2	0	0
		12	2	0	0
		15	2	0	0
April 25	Thickson	3	2	0	0
		5	2	2	0
		7	2	0	0
		9	2	0	0
		12	2	0	0
		15	2	0	0

APPENDIX 2 B CONTINUED

Date	Location	Depth (m)	# Samples	# Whitefish	# Others
April 30	Thickson	3	2	0	0
		5	2	0	0
		7	2	0	1 smelt egg
		9	2	0	0
		12	2	0	0
		15	2	0	0
	TOTALS		96	6	9 smelt eggs

APPENDIX 3 A
PICKERING 1984 SUBSTRATE COMPOSITION
(DIVER ESTIMATES)

WHITBY WEST SITE:

PERCENTAGE COMPOSITION

Depth (m)	slate	boulder	cobble	gravel	sand	clay	silt
1	--	25	5	--	70	--	--
2	--	15	65	10	10	--	--
3	--	15	60	5	20	--	--
4	--	25	25	--	50	--	--
5	--	20	60	--	20	--	--
6	--	5	60	--	35	--	--
7	--	4	40	8	8	40	--
8	35	30	5	15	--	--	15
9	70	10	20	--	--	--	--
10	80	20	--	--	--	--	--
11	--	10	45	10	20		15
12	3	12	75	--	4	--	6

THICKSON POINT SITE:

PERCENTAGE COMPOSITION

Depth (m)	slate	boulder	cobble	gravel	sand	clay	silt
1	--	--	--	--	100	--	--
2	--	5	15	--	80	--	--
3	--	5	80	10	5	--	--
4	--	5	80	10	5	--	--
5	--	5	64	15	--	15	1
6	--	--	49	--	--	30	1
7	--	5	59	10	--	25	1
8	--	5	75	5	--	15	--
9	--	5	55	--	13	15	12
10	--	5	50	--	25	--	20
11	--	5	70	5	10	--	10
12	--	--	50	--	25	--	25

APPENDIX 3 B
PICKERING 1984 SUBSTRATE COMPOSITION
(FROM PHOTOGRAPHS)

Loc	Depth	Film	Slide#	Comments
WW	1 E	B	7,8	100% sand in ridges about 10 cm apart
	1 C	B	9,10	small boulder with algae, about 70% sand
	1 W	B	11,12	boulder/cobble with sand between rocks
		- Large amount of sand makes spawning unlikely, potential of small boulder/ cobble patches poor.		
WW	2 E	B	1,2	boulder/cobble/gravel, heavy algal growth
	2 C	B	3,4	cobble, heavy algal growth, some sand.
	2 W	B	5,6	as above
		- Poor spawning potential due to depth, Cladophora cover, some sand, few spaces between rocks.		
WW	3 E	A	13	large algae covered boulder, clean cobble & gravel.
		- Only 1 slide from site. Suggests reasonably good spawning potential.		
WW	4 E	A	7,8	boulder/cobble with sand between stones
	4 C	A	9,10	cobble/gravel, heavy algae
	4 W	A	11,12	cobble/gravel, less algae
		- Generally patchy, marginal to poor for spawning		
WW	5 E	B	13,14	cobble/gravel with some sand between rocks
	5 C	B	15,16	boulder/cobble/gravel, sand between rocks
	5 W	B	17,18	cobble/gravel, spaces cemented with sand
		- Spawning potential fair to good, but limited spaces between stones. Substrate fairly clean.		
WW	6 E	C	1,2	cobble with some sand between stones
	6 C	C	3,4	boulder/cobble/gravel, a little sand between
	6 W	C	5,6	as above, but less sand between stones
		- Spawning potential fair to good, but limited spaces for eggs to settle between stones.		
WW	7 E	C	8,9	boulder/cobble/gravel cemented into sand bed
	7 C	C	10,11	cobble/gravel, quite clean
	7 W	C	12,13	boulder/cobble, sand between stones
		- Spawning potential poor to good. Substrate quite clean but substantial sand to east of site.		
WW	8 E	D	1	some cobble/gravel, mostly soft sand or silt
	8 C	D	2,3	slate/boulder/cobble with fine silt covering
	8 W	D	4,5	slate/boulder with fine silt cover
		- Spawning potential poor in silty areas, fair to good in areas of slate slabs.		

Loc	Depth	Film	Slide#	Comments
WW	9 E	C	14,15	slate/boulder in sand bed, sand over stones
	9 C	C	16,17	boulder/cobble, sand over & between stones
	9 W	C	18,19	boulder/slate/cobble, fine sand/silt cover
				- Spawning potential poor in sandy areas, fair to good elsewhere.
WW	10 E	D	6,7	slate slabs/boulder, spaces between slabs
	10 C	D	8,9	slate sabs embedded in silty material
	10 W	D	10,11	slate/boulder embedded in silty material
				- Spawning potential good, especially in east photo. Spaces between slate slabs should offer protection.
WW	11 E	D	12,13	cobble in soft silty sand, poor potential
	11 C	D	14,15	as above, but more cobble
	11 W	D	16,17	sand/silt, 20% embedded cobble
				- Spawning potential very poor to poor. Large amount of soft material, no spaces for eggs to settle into.
WW	12 E	E	1,2,3	cobble embedded in silty sand, silt cover
	12 C	E	4,5	as above, but smaller cobble
	12 W	E	6,7	cobble/gravel in sand/silt, some algae
				- Spawning potential very poor. Abundant fines and no protection for eggs.
TP	1			No photo. Substrate 100% sand. Entirely unsuitable for spawning.
TP	2 E	E	10,11	cobble in sand, 10-15 cm Cladophora
	2 C	E	12,13	50% cobble, 50% sand, 3-5 cm Cladophora
	2 W	E	14,15	10% cobble in sand, little algae
				- Spawning potential almost nil due to depth and sand.
TP	3 E	E	16,17	cobble, sand between stones, 50% Cladophora
	3 C	E	18,19	boulder/cobble, fine cover of sand or silt
	3 W	E	20,21	boulder embedded in clay or sand
				- Spawning potential poor to fair. Best at centre site.
TP	4 E	F	1,2	boulder/cobble/gravel, quite clean
	4 C	F	3,4	as above, mostly cobble
	4 W	F	5,6	as above, with large boulder, poorest site
				- Spawning potential fair to very good. Spaces between stones to provide protection for eggs.
TP	5 E	F	7,8	boulder/cobble, some silt, quite clean
	5 C	F	9,10	boulder/cobble/gravel, some sand & silt
	5 W	F	11,12	boulder/cobble/gravel, quite clean
				- Spawning potential good to very good, best at east and west sites.

APPENDIX 3 B CONTINUED

Loc	Depth	Film	Slide#	Comments
TP	6 E	F	13,14	hardpan clay with a bit of gravel
	6 C	F	15,16	boulder/cobble embedded in clay
	6 W	F	17,18	boulder/cobble piled on hardpan clay
			- Spawning potential from very poor to very good. Little potential on hardpan clay (east), but very good potential where clean boulders & cobble are piled on hardpan (west site).	
TP	7 E	G	1,2	cobble/boulder, quite clean
	7 C	G	3,4	boulder/cobble in clay
	7 W	G	5,6	a few boulders in clay, poor potential
			- Spawning potential poor at west site, very good in cobbles and boulder at east site.	
TP	8 E	G	7,8	cobble on clay, silt covering
	8 C	G	9,10	cobble/boulder on clay, silt covering
	8 W	G	11,12	cobble on clay, less silt
			- Spawning potential poor to fair. Limited spaces between stones, quite a lot of silt.	
TP	9 E	G	13,14	boulders in silt
	9 C	G	15,16	boulder/cobble in silt/clay
	9 W	G	17,18	cobble on clay with silt covering
			- Spawning potential very poor to poor. Clay provides no protection, siltation excessive.	
TP	10 E	H	1,2	cobble in silt/clay, silt covering
	10 C	H	3,4	cobble/boulder in silt
	10 W	H	5,6	cobble/boulder in silt/sand
			- Spawning potential very poor, few spaces between rocks filled with fines, substantial silt covering.	
TP	11 E	H	7,8	cobble/boulder pile, some sand in spaces
	11 C	H	9,10	as above, but more sand/silt
	11 W	H	11, 12	boulder/cobble/gravel, some silt in spaces
			- Spawning potential fair to good, much better than 8 to 10 m range.	
TP	12 E	H	13,14	boulder/gravel in bed of silty sand
	12 C	H	15,16	boulder/gravel in silty sand
	12 W	H	17,18	gravel in silty sand
			- Spawning potential nil to very poor, due to excessive fine material.	

APPENDIX 3 C
SUBSTRATE PARTICLE SIZE CLASSIFICATION

Slate:	> 300 mm (mostly flat slabs)
Boulder:	> 254 mm
Cobble:	64 - 254 mm
Pebble:	8 - 64 mm
Gravel:	2 - 8 mm
Sand:	0.063 - 2 mm
Clay:	0.001 - 0.063 mm
Silt	< 0.063 mm, high organic content

The above particle sizes are used for classification of substrates by screening. In the present study, substrate composition was estimated visually (by divers or from substrate photos), using these particle size ranges as a guide.

APPENDIX 4 A
SPAWNING SUBSTRATE SUITABILITY INDEX
USED FOR EVALUATION OF SUBSTRATE PHOTOGRAPHS

ing	Description
	pure sand, silt, hardpan clay, or very dense Cladophora
	small amount of boulder/cobble/gravel embedded in fines
	boulder/cobble/gravel > 25%, embedded in fines
	boulder/cobble/gravel > 50%, embedded in fines
	boulder/cobble > 80%, spaces between filled with fines
	boulder/cobble with moderate amount of fines in spaces
	boulder/cobble with only a few fines in spaces
	boulder/cobble in >1 layers, a few fines between
	boulder/cobble in > 2 layers, a few fines between
	boulder/cobble in > 2 layers, very clean
	clean cobble or boulder bed, many layers deep, many spaces for eggs to settle into substrate, no fines

APPENDIX 4 B
EVALUATION OF SUBSTRATE PHOTOGRAPHS
FOR SPAWNING SUITABILITY

	WHITBY WEST SITE				THICKSON POINT SITE			
Depth	East	Centre	West	Mean	East	Centre	West	Mean
1	0	1	5	2.0	0	0	0	0.0
2	2	3	2	2.3	0	1	0	0.3
3	6	-	-	6.0	3	4	3	3.3
4	2	3	5	3.3	7	6	5	6.0
5	6	5	6	5.7	7	6	7	6.7
6	5	6	7	6.0	2	4	7	4.3
7	4	7	6	5.7	7	6	3	5.3
8	2	6	5	4.3	3	4	5	4.0
9	3	5	6	4.7	3	2	1	2.0
10	7	6	6	6.3	1	2	2	1.7
11	3	4	2	3.0	6	3	6	5.0
12*	5,0	4,1	3,2	2.5	1	2	0	1.0

*Two sets of photographs were taken at the 12 meter depth at Whitby West.

APPENDIX 5 A
ROUND WHITEFISH EGG INCUBATION EXPERIMENT
THICKSON POINT - DATA SUMMARY

Date (Week)	Temp oC	Turbidity N.T.U.	Dev Stage	# Live Eggs	#Hatched Larvae Live	Dead	% Survival
11/12/84	3.1	------	0	150	---	---	100
(0)			0	150	---	---	100
04/02/85	0.4	3.0	13-14	104	---	---	69.3
(8)			13-14	104	---	---	69.3
13/03/85	2.2	4.5	16	92	---	---	61.3
(13)			16	76	---	---	50.7
04/04/85	3.2	Visibility	18-19	97	2	1	66.0
(16)		0.3 m	18-19	118	3	0	80.7
17/04/85	5.0	0.5 m	20	3	47	24	33.3
(18)			20	5	41	11	30.7
26/04/85	4.8	-----	20	0	1	37	0.6
(19)			20	0	0	50	0.0

APPENDIX 5 B
ROUND WHITEFISH EGG INCUBATION EXPERIMENT
RICHARDSON POINT - DATA SUMMARY

Date (Week)	Temp oC	Turbidity N.T.U.	Dev Stage	# Live Eggs	#Hatched Larvae Live	Dead	% Survival
11/12/84	3.4	------	0	150	---	---	100
(0)			0	150	---	---	100
04/02/85	1.4	2.8	15	91	---	---	60.7
(8)			14-15	98	---	---	65.3
13/03/85	3.8	21.0	16-17	88	---	---	58.7
(13)			16-17	74	---	---	49.3
04/04/85	5.1	Visibility	20	21	36	18	38.0
(16)		0.0 m	20	17	45	2	41.3
17/04/85	5.0	0.6 m	20	1	7	15	5.3
(18)			20	0	0	0	0.0
26/04/85	5.7	-----	20	0	0	21	0.0
(19)			20	0	0	8	0.0

APPENDIX 5 C
ROUND WHITEFISH EGG INCUBATION EXPERIMENT
SIMCOE POINT - DATA SUMMARY

Date (Week)	Temp oC	Turbidity N.T.U.	Dev Stage	# Live Eggs	#Hatched Larvae Live	Dead	% Survival
11/12/84	3.1	------	0	150	---	---	100
(0)			0	150	---	---	100
04/02/85	0.2	------	15	105	---	---	70.0
(8)			15	103	---	---	68.7
13/03/85	3.4	6.1	16-17	81	---	---	54.0
(13)			16-17	100	---	---	66.7
04/04/85	3.8	Visibility	20	33	39	9	48.0
(16)		0.6 m	20	27	27	10	36.0
17/04/85	4.6	1.5 m	20	0	6	64	4.0
(18)			20	0	12	7	8.0
26/04/85	4.9	-----	20	0	0	21	0.0
(19)			20	0	0	11	0.0

APPENDIX 5 D
ROUND WHITEFISH EGG INCUBATION EXPERIMENT
PICKERING 'B' 7 meters - DATA SUMMARY

Date (Week)	Temp oC	Turbidity N.T.U.	Dev Stage	# Live Eggs	#Hatched Larvae Live	Dead	% Survival
11/12/84	4.1	------	0	150	---	---	100
(0)			0	150	---	---	100
06/02/85	0.2	------	14-15	57	---	---	38.0
(8)			14-15	65	---	---	43.3
13/03/85	4.2	21.5	17-18	59	---	---	39.3
(13)			17-18	41	---	---	27.3
04/04/85	2.5	Visibility	19-20	59	19	2	52.0
(16)		2.4 m	19-20	54	1	7	36.7
17/04/85	5.0	1.5 m	20	1	9	10	6.7
(18)			20	0	9	18	6.0
26/04/85	5.1	-----	20	0	0	21	0.0
(19)			---	--	--	--	---

(chamber could not be removed)

APPENDIX 5 E
ROUND WHITEFISH EGG INCUBATION EXPERIMENT
PICKERING 'B' 5 meters - DATA SUMMARY

Date (Week)	Temp oC	Turbidity N.T.U.	Dev Stage	# Live Eggs	#Hatched Larvae Live	Dead	% Survival
11/12/84	4.5	------	0	150	---	---	100
(0)			0	150	---	---	100
04/02/85	2.7	3.1	15-16	84	---	---	56.0
(8)			15-16	51	---	---	34.0
13/03/85	6.2	26.5	19-20	42	6	12	32.0
(13)			19-20	15	4	1	12.7
04/04/85	5.0	Visibility	20	0	1	1	0.7
(16)		0.0 m	20	0	0	0	0.0
17/04/85	9.5	1.0 m	20	0	0	1	0.0
(18)			20	1	3	14	2.7
26/04/85	6.9	-----	20	0	0	5	0.0
(19)			20	0	0	4	0.0

APPENDIX 5 F
ROUND WHITEFISH EGG INCUBATION EXPERIMENT
ROUGE RIVER - DATA SUMMARY

Date (Week)	Temp oC	Turbidity N.T.U.	Dev Stage	# Live Eggs	#Hatched Larvae Live	Dead	% Survival
11/12/84	4.3	------	0	150	---	---	100
(0)			0	150	---	---	100
04/02/85	0.2	2.6	14	46	---	---	30.7
(8)			14	62	---	---	41.3
13/03/85	1.4	220.0	16	57	---	---	38.0
(13)			16	47	---	---	31.3
04/04/85	2.8	Visibility	19-20	14	3	1	11.3
(16)		0.0 m	19-20	13	2	1	10.0
17/04/85	6.0	1.0 m	20	0	1	1	0.7
(18)			20	2	4	8	4.0
26/04/85	5.2	-----	20	0	0	8	0.0
(19)			20	1	1	15	1.3

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